PLATE III
PAPER NO. 245

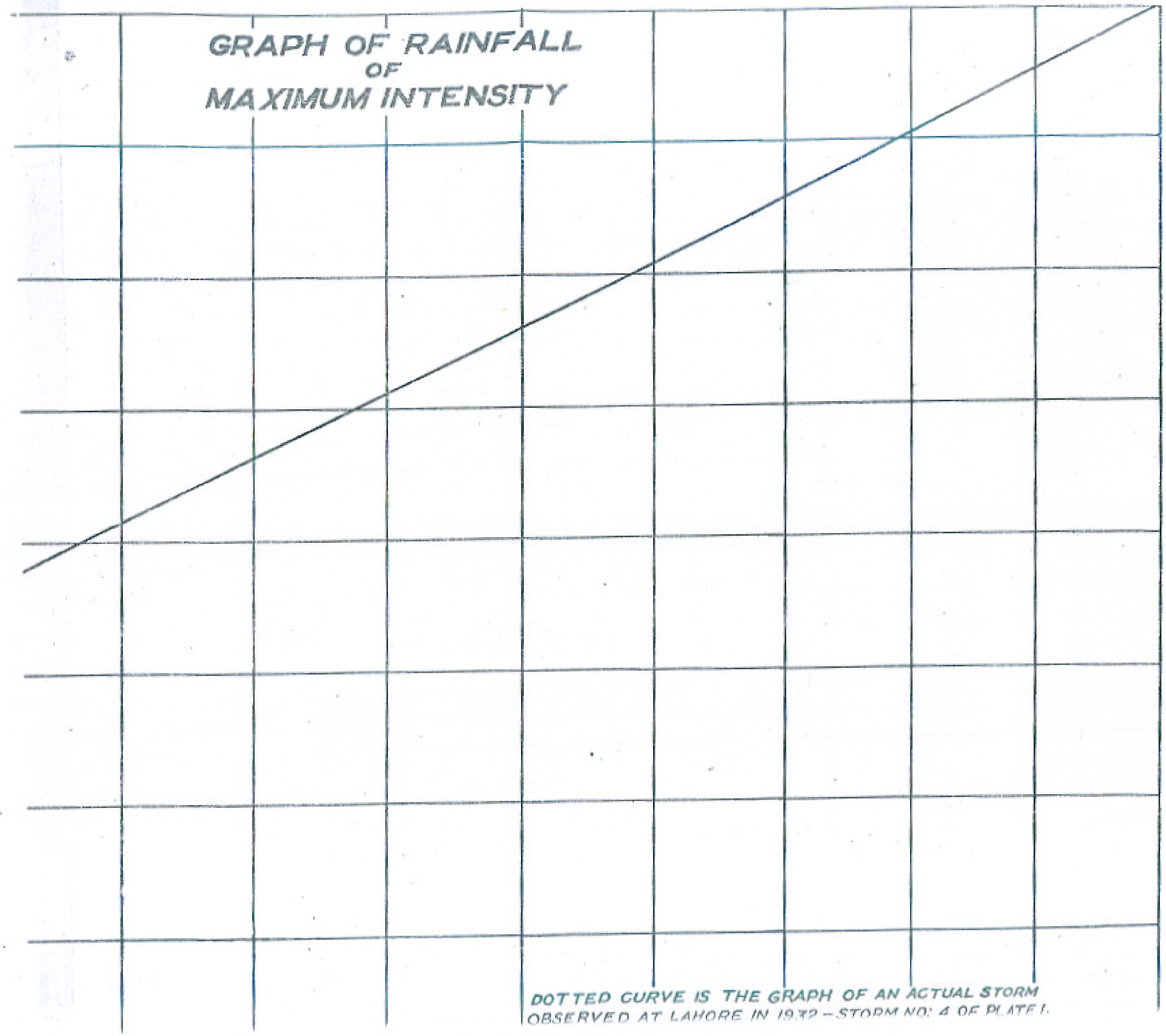
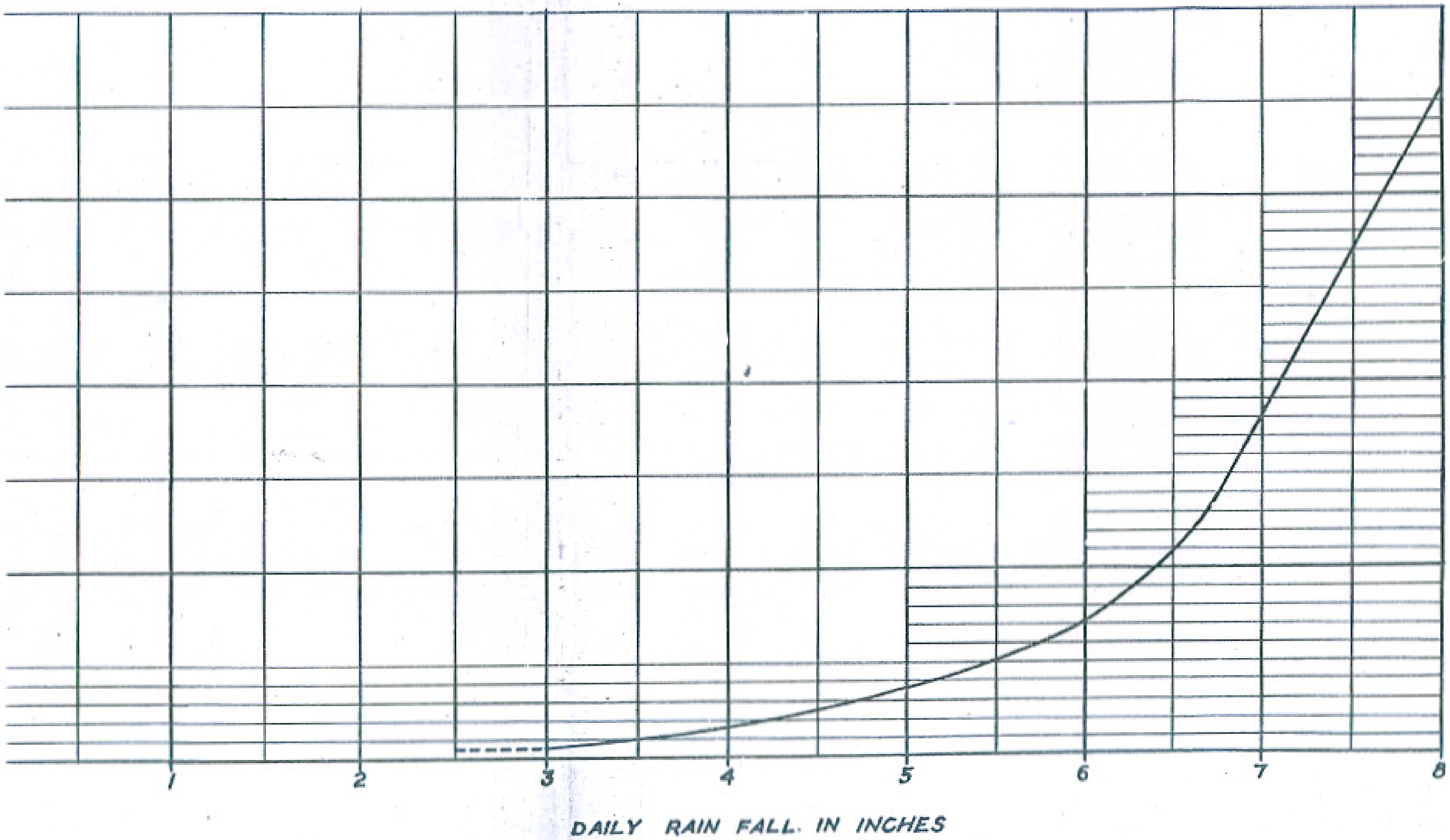
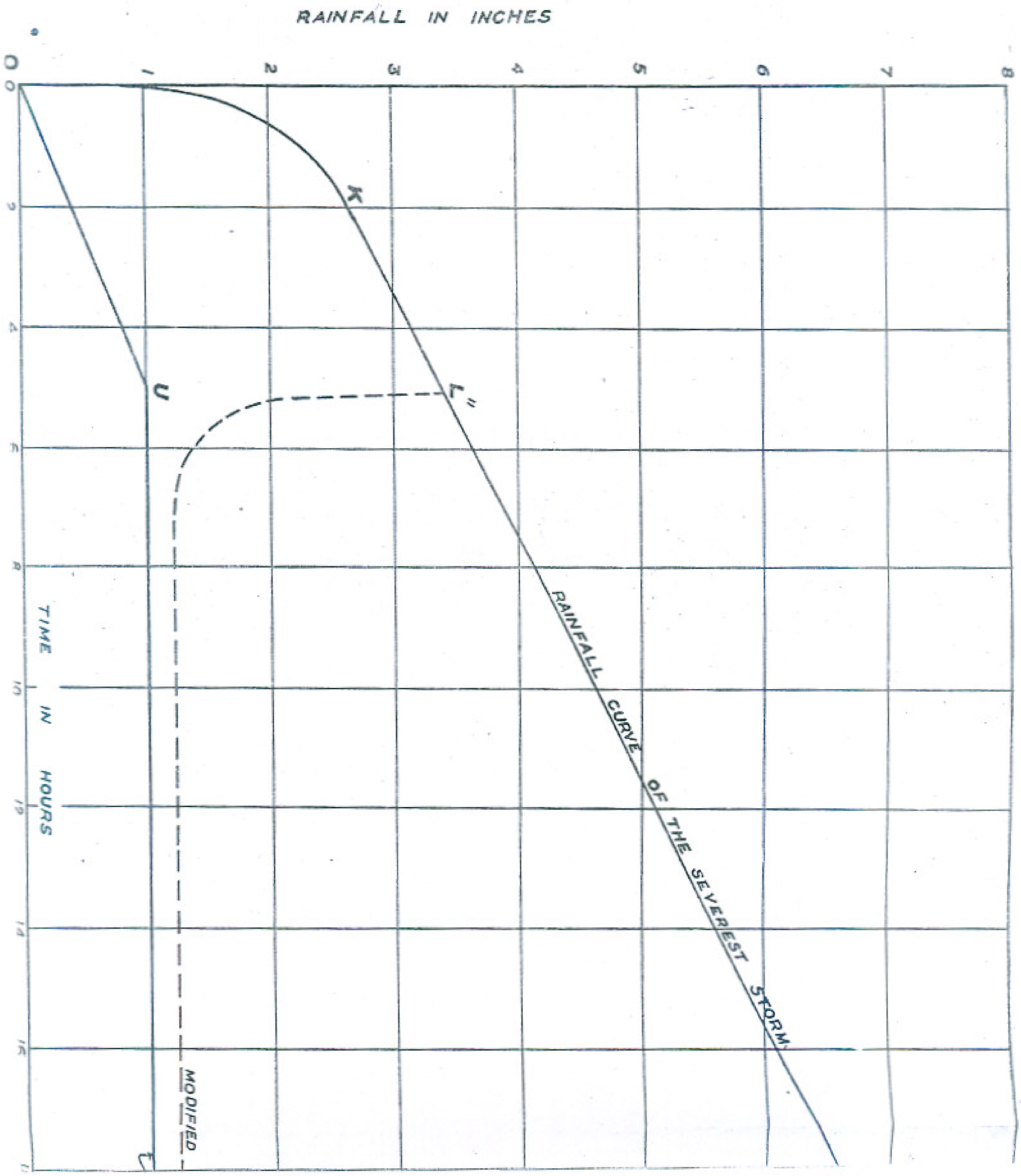


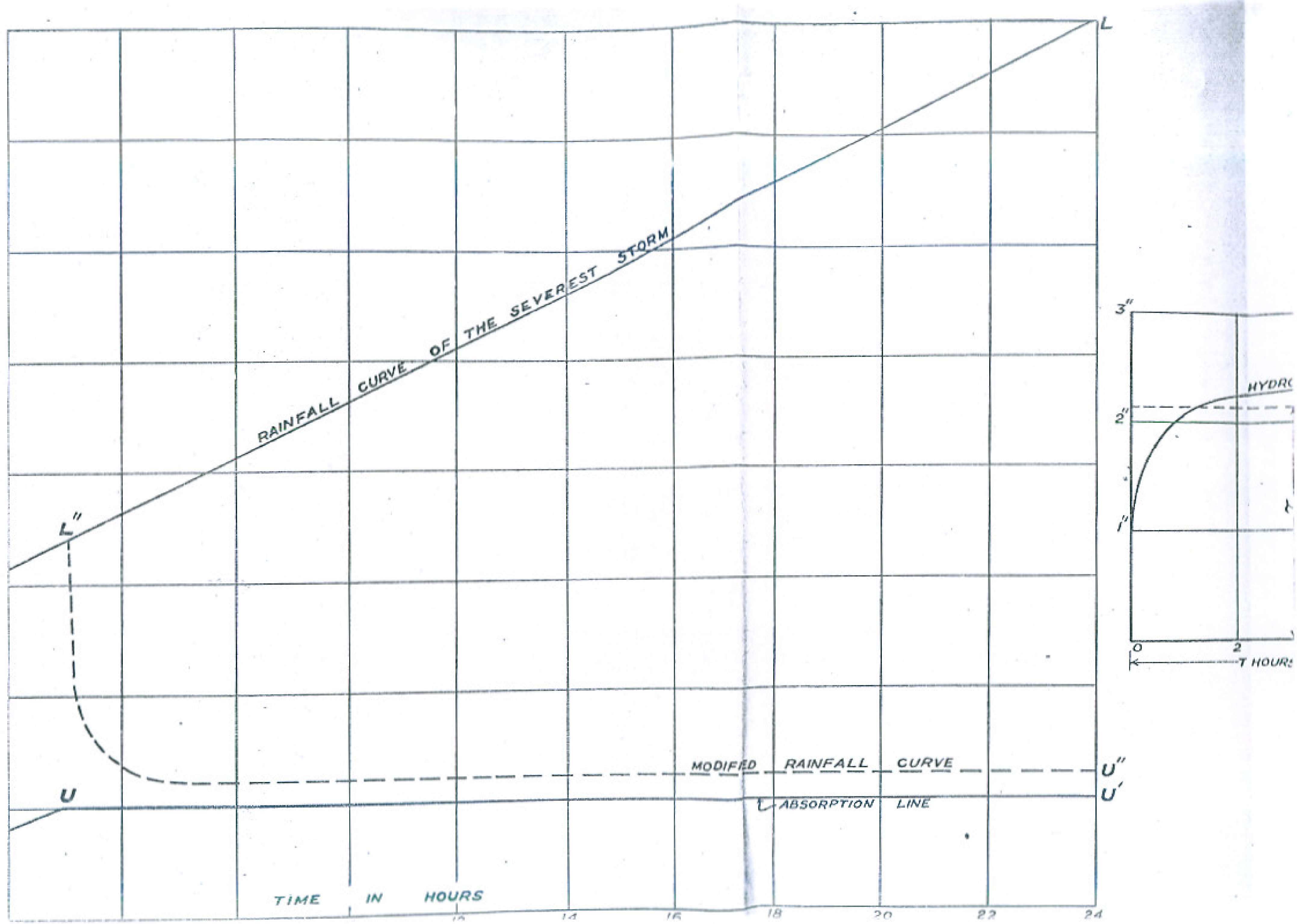
PLATE IV
PAPER NO. 245

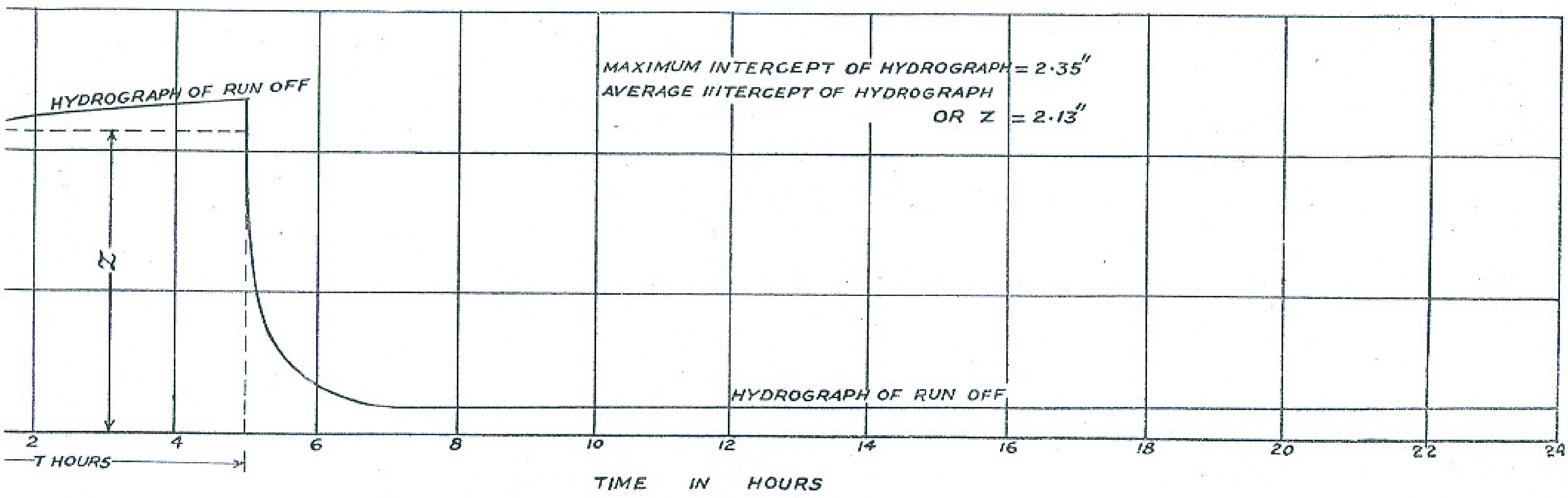
RAINFALL FREQUENCY CURVE
FOR
GUJRANWALA DISTRICT (PUNJAB)



PUNJAB ENGINEERING CONGRESS
1941.

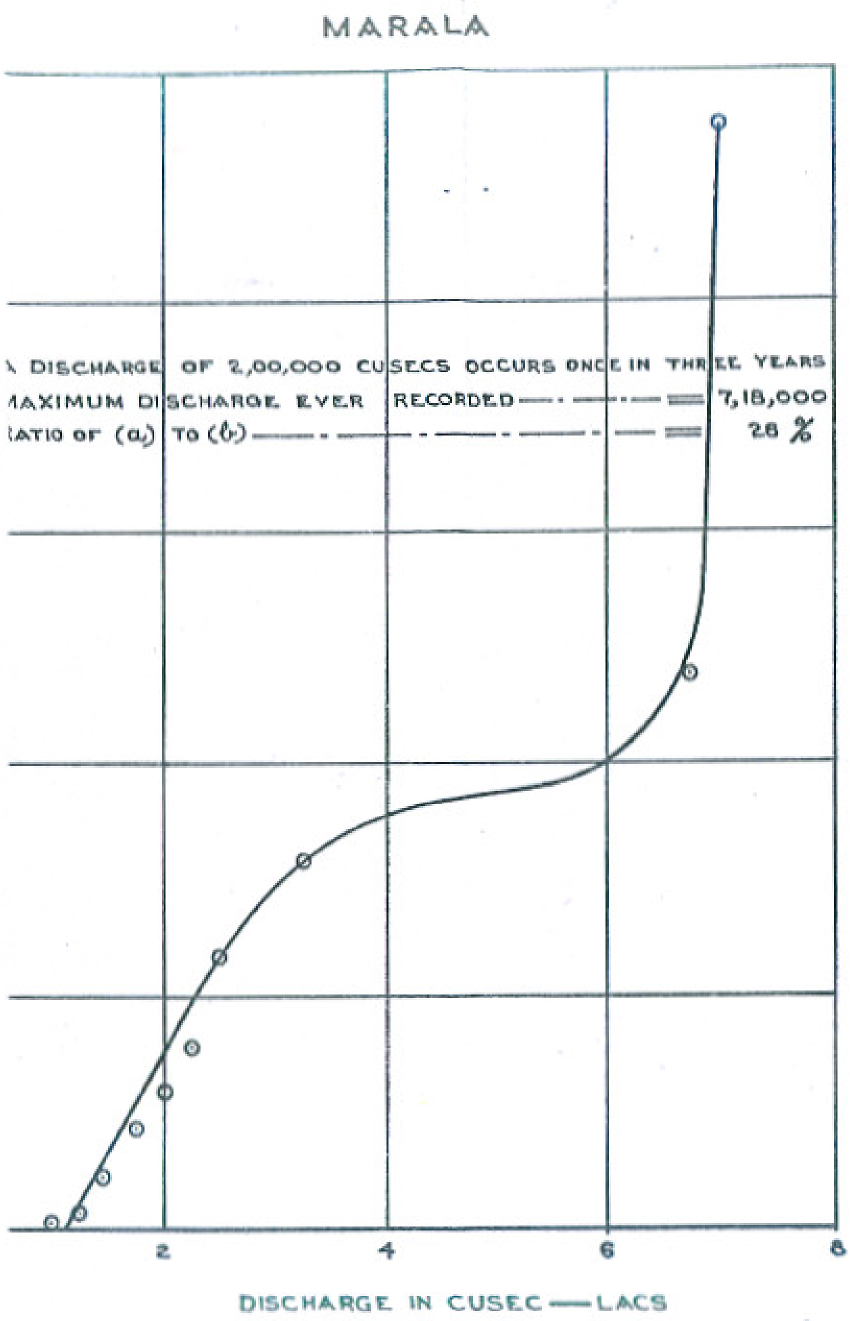

RAINFALL IN INCHES
0
1
2
3
4
5
6
7
8
K
U
L''
TIME IN HOURS
RAINFALL CURVE OF THE SEVEREST STORM
MODIFIED


L
L″
RAINFALL CURVE OF THE SEVEREST STORM
MODIFIED RAINFALL CURVE
U″
U
U′
ABSORPTION LINE
TIME IN HOURS
14
16
18
20
22
24
3″
2″
1″
0
2


HYDROGRAPH OF RUN OFF
MAXIMUM INTERCEPT OF HYDROGRAPH = 2·35"
AVERAGE IITERCEPT OF HYDROGRAPH
OR Z = 2·13"
Z
HYDROGRAPH OF RUN OFF
2
4
6
8
10
12
14
16
18
20
22
24
T HOURS
TIME IN HOURS

FLOOD FREQUENCY CURVES

PLATE VI
PAPER No. 245



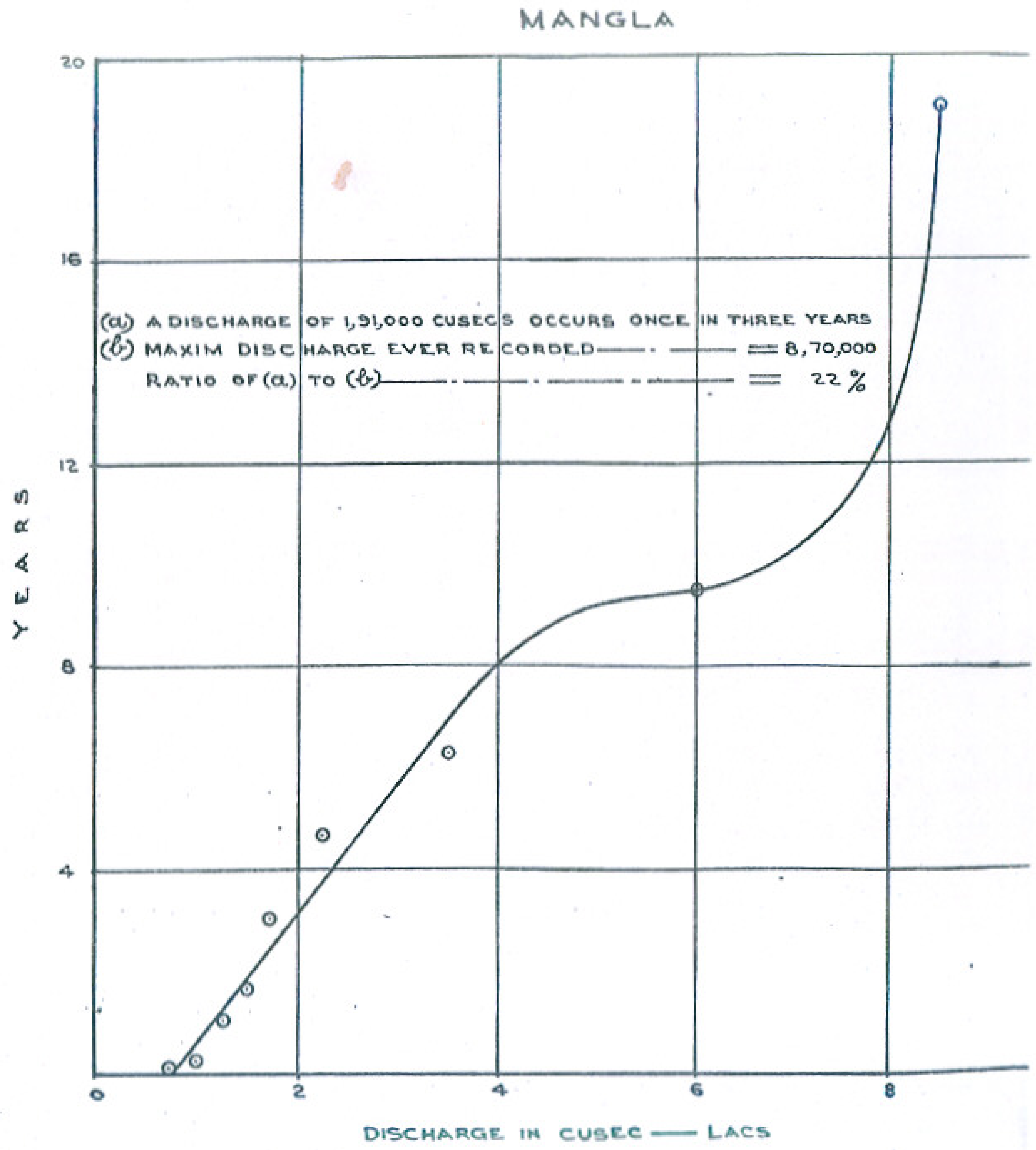
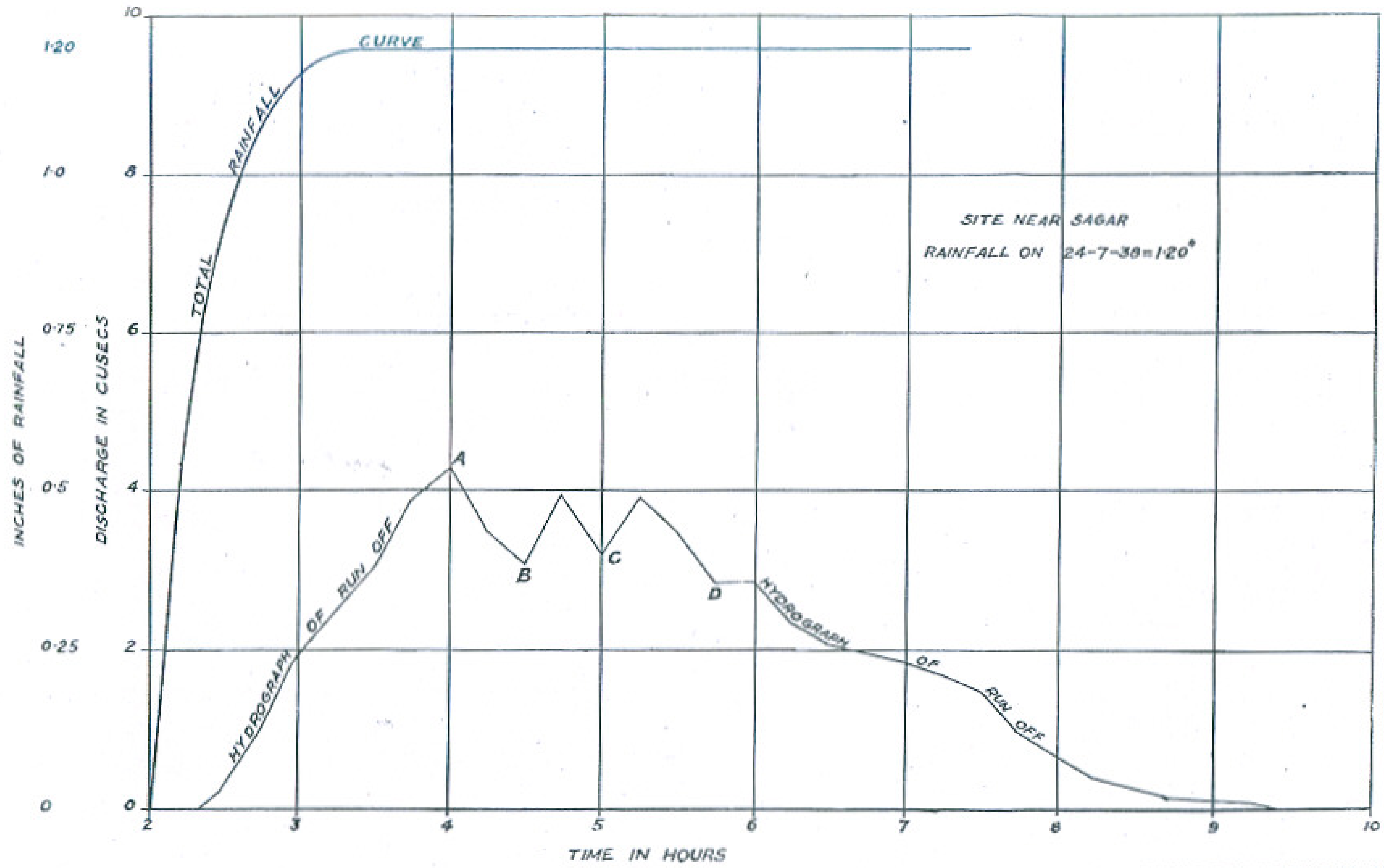


PLATE VII

PAPER NO. 245



PUNJAB ENGINEERING CONGRESS 1941.

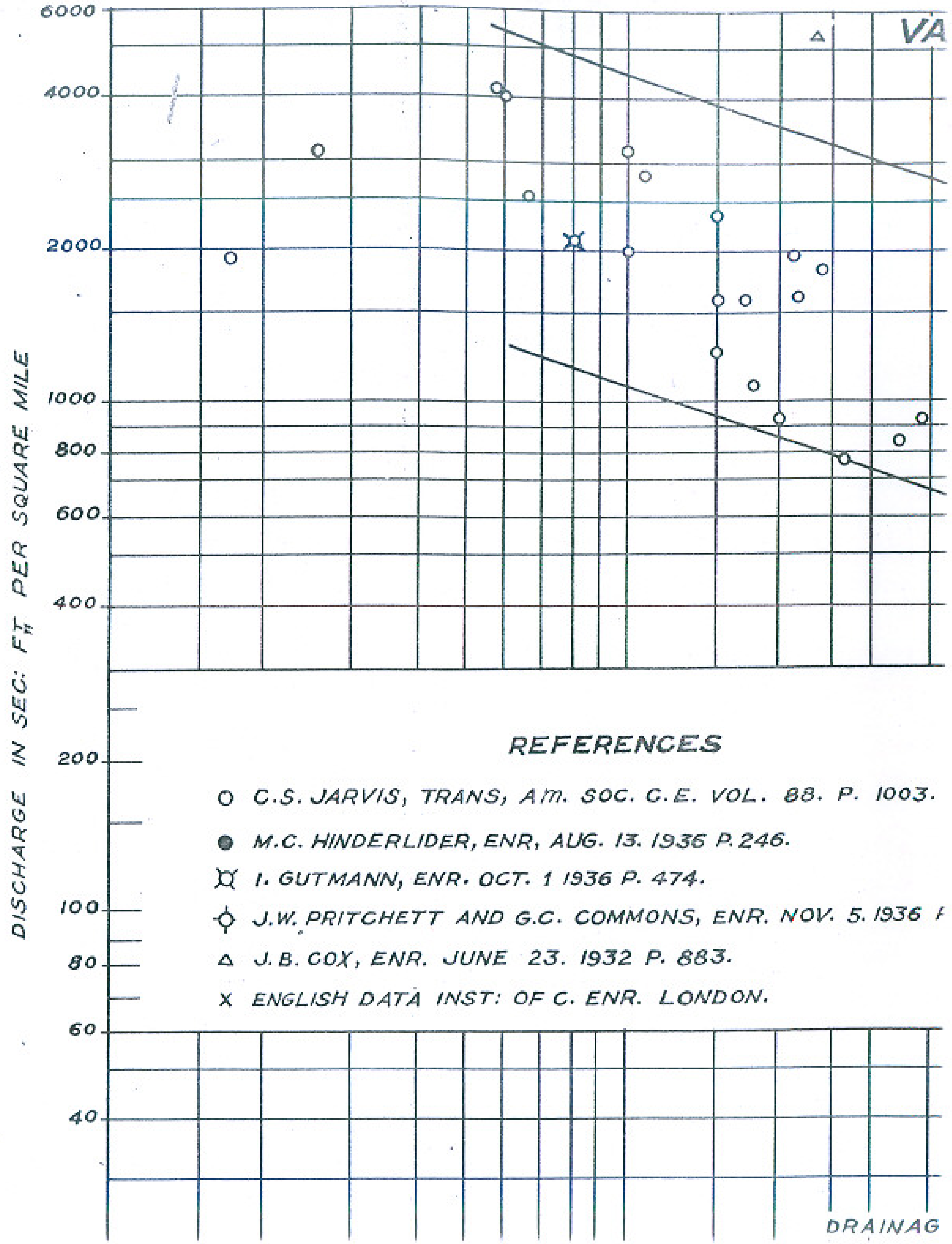
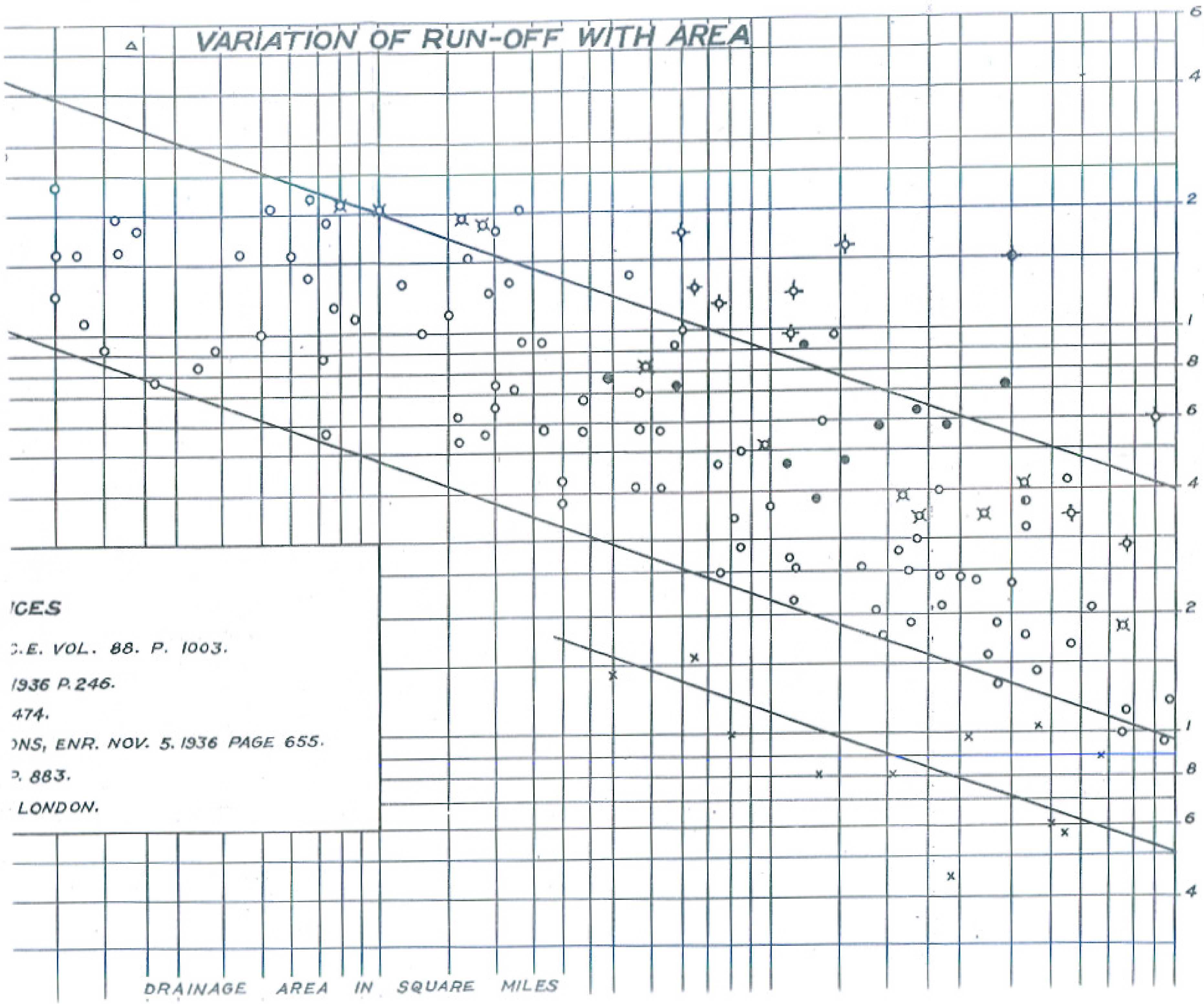

VA
6000
4000
2000
1000
800
600
400
200
100
80
60
40
DISCHARGE IN SEC: FT PER SQUARE MILE
REFERENCES
C.S. JARVIS, TRANS, Am. SOC. C.E. VOL. 88. P. 1003.
M.C. HINDERLIDER, ENR, AUG. 13. 1936 P.246.
I. GUTMANN, ENR. OCT. 1 1936 P. 474.
J.W. PRITCHETT AND G.C. COMMONS, ENR. NOV. 5. 1936
J. B. COX, ENR. JUNE 23. 1932 P. 883.
ENGLISH DATA INST: OF C. ENR. LONDON.
DRAINAG

PLATE VIII

PAPER No. 245



DISCUSSION

In introducing the Paper *Mr. N. D. Gulhati* said that the phenomenon of rainfall runoff was of such varied interest that everyone of those present must have been faced with some aspect of this intriguing problem at one time or another. In the Paper he was presenting to the Congress, the problem had been dealt with particular reference to only one such aspect *viz.*, the determination of the capacity of storm water drains.

He stated that a very large number of such drains had been constructed in this province during the last few years, and that in the Rechna Doab alone there were about 1,000 miles of these drains.

In the past, these drains were given arbitrary capacities and the strongest argument given for adopting a particular section for a drain used to be that the Chief Engineer during a discussion on the case had suggested such section. During recent years drains had been designed for capacities worked out on the basis of 1 to 4 cusecs per square mile of catchment area. The actual figure adopted was in many cases fixed on considerations that were not wholly relevant. Some of the four-cusecs drains had been called upon to pass as much as three times their designed discharge while others had not got even $\frac{1}{4}$th of what they were designed for. He pointed out that it was therefore high time that the design of storm water drains was placed on sounder basis.

The speaker said that the immediate or exciting cause of all surface flow was rainfall and in Chapter II of this Paper various problems connected with rainfall had been discussed in detail. The most important point brought out was the necessity of increasing the number of rain gauges in the province, and providing Automatic Integrating recorders to the extent of at least 10% of the total number. The expenditure involved on such gauges would not be heavy. He said that for the Lower Chenab Canal area it would cost only Rs. 5,000 to instal the additional rain gauges. The cost of an integrating rain gauge was Rs. 300. Through the courtesy of Dr. Bose one such gauge had been placed there for the inspection of the members of the Congress.

He pointed out that in Chapter III of this Paper factors other than rainfall had been discussed and an attempt had been made to evaluate their effect on runoff.

He stated that rainfall being the direct cause of runoff an attempt had been made in Chapter IV to evolve a method for the determination of runoff from a known rain storm. The method although somewhat complicated in its derivation was according to the speaker, simple in its application, since all that was needed was the graph of a rainfall curve as produced by an automatic rainfall recorder. If the absorption line was drawn on it, the intercepts between the graph of the storm and the absorption line gave the hydrograph of runoff.

This method had been based on a number of assumptions that were described in detail in the Paper. The effect of these assumptions and the necessary corrections that required to be made were detailed in Chapter V. Although the assumptions would never hold in practice, the mean results obtained would generally be true.

To fix the capacity of a drain it was necessary to know the type of storm that occurred frequently in the catchment of a drain. As an example if in a particular catchment the rainfall represented by a certain graph occurred say once every year the required capacity of a drain in that catchment could be straightway determined from that particular graph by the method explained in Chapter IV of the Paper.

Unfortunately such data had never been collected in this country, and consequently it became necessary to fall back upon some indirect method for the determination of required capacities of drains. With this end in view a graph of rainfall that could occur in the plains of the Punjab with the maximum possible intensity had been produced analytically. This was shown on Plate III. This graph although obtained from the data available in the Lower Jhelum Canal area should be applicable all over the province, and in its earlier part which was the one most commonly needed, this rainfall graph represented the maximum rainfall that could occur at any place in the plains over a very large area of the world. What happened in the hills was that the earlier part of this graph recurred more frequently than was possible in the plains. From this graph of maximum rainfall, the maximum runoff in a particular catchment had been determined by the method explained in Chapter IV of the Paper. To work out the normal runoff from the maximum the authors had taken the analogy of rivers, and had found that the intensity of a normal runoff would be about $\frac{1}{4}$th that of the maximum runoff.

The method of converting rainfall to runoff as shown in the Paper was according to the speaker applicable to such areas only in which the intensity of rainfall did not vary appreciably. Such areas he said must necessarily be small. The application of the method to large areas had been discussed in Chapter VI where a general formula had been evolved. The values of M and Ao as given there were only indicative and for want of sufficient data the authors inspite of their best efforts could not obtain anything more definite. The speaker hoped that in years to come data would be collected from which it would be possible to determine these values more definitely.

In conclusion the speaker stated that the lines on which further data should be collected were noted in Chapter VII. This was a very important matter and the authors desired to draw the attention of the authorities that be, to the necessity of taking very early steps for the collection of this data.

For the last three years rainfall and runoff data for the more important drains was being collected systematically in the Drainage Circle. Although special precautions were being taken to obtain reliable figures of total daily rainfall and the resulting runoff, no notice was being taken of factors other than rainfall which collectively were probably more important than rainfall itself.

Mr. James L. Roy said that he knew the authors were writing a Paper this year touching on drains; but only had an opportunity to read it a couple of days earlier. According to the speaker the Paper broke new ground at the Congress to a great extent and was admirably presented. The authors deserved great credit for the work they had put into it.

The Paper presented clear ideas which might well be worked up into valuable methods of design of drains in the future. The subject of drains in all its aspects was rapidly gaining in importance in this province, while the extent of the drainage system was probably not fully recognised by many. Some idea could be had from the fact that at the end of March 1940 there were in the Chaj and Rechna Doabs alone :—

1,243 miles of Main and Branch Drains completed and 203 miles of Branch Drains under construction while new drains were contemplated when the financial condition improved. Those drains made Land Reclamation possible in high water table areas. All that made no reference to other successful drainage systems especially on the Sirhind and Upper Bari Doab Canals. The speaker then touched on a few important points in the Paper :

On page 138 end of paragraph 8 the authors had made certain suggestions for augmenting existing R. G. Stations, this was undoubtedly required. The speaker said he had been making enquiries from certain Superintending Engineers regarding possible additional seasonal sites. The replies showed that in the Chaj and Rechna Doabs it was possible to put down just as many R. Gs. as proposed in this Paper and he trusted that this would be done. The value of integrating rain gauges was self apparent. Everything depended on satisfactory rain gauging.

Plate IV was of interest and might with advantage be plotted for any catchment in which a new drain was proposed—but it depended on better data than was available at the time.

Chapter III dealt quite fully with the factors influencing the runoff. In irrigated tracts one could expect cultivation with its attendant ploughing and watbandi, but not all the ground was cultivated; there were often large deflocculated areas—*pat*—the intensity of runoff from those two types differed immensely and was probably the most important factor in the runoff.

Table V on page 145. All that the speaker would say about this table was that it would be invaluable if it were of proved reliability. The speaker trusted that the authors would carry on their good work in this direction.

On page 157 in paragraph 1 the authors had made definite proposals for the capacities of drains in the irrigated tracts in the Punjab. They proposed to work on intensities of discharge likely to be attained once in 3 years. The speaker wanted to know why 3 years and not some other figure ?

They had fairly good discharge records since 1938 and comparing the maximum discharge in the 3 years since then with the record, in the case of following drains, the speaker did not find that the authors' proposals would meet the case.

		Maximum in 3 years.	Previous record.
A. V. Drain	..	930	1571 in 1933
A. K. N. Drain	..	181	1500 in 1933
Mona Drain	..	411	238 in 1936
Macchhiana Drain	..	201	138 in 1933
Wan Drain	..	39	400 in 1934

The speaker suggested that a more rational method would be to work on the maximum discharge for 10 years and design the drain to remove the flood water in 3 days; that was a period which would not harm kharif crops. This connoted a knowledge of past discharge in similarly situated areas. That was where the statistical record of the runoff in drains, which was maintained in the Drainage Circle, came in. In about another 7 years this record would become really valuable. Incidentally, the authors referred to the lack of this information on page 165 paragraph 2. Regarding paragraph 3 on page 158 the speaker did not think that any analogy could be made between the River floods at Mangla and Marala and Drainages on the Punjab plains. The size, slope and character of the catchments varied very much.

The description of the run off during a particular rain storm on page 163 was most instructive. The speaker wished that officers who had opportunities would make such observations and let the Drainage Circle have the results.

In paragraph 2 page 171 the authors had put forward sound suggestions regarding the collection of further data. The suggestion at the latter part of sub-para 1 was a particularly good one and it was hoped would be carried out at some sites at least, say where Rain gauges were read by canal signallers.

Rai Bahadur A. N. Khosla said that the Paper was the second of this nature presented before the Congress and was a welcome departure from the traditional type. It was gratifying he said to note that the authors had continued to pursue with zeal, the study of this subject in which the Punjab Engineers had shown little interest so far, but which was one of fundamental importance in all irrigation, water supply, drainage, sanitation, flood control and hydro-electric projects. The authors according to the speaker had taken pains in the collection of the data, and had presented it in an understandable form. In many respects their approach to the subject was original and they deserved to be complimented on this. The graph of rainfall of maximum intensity (Plate III) was of particular value and appeared to be of wide application.

Rainfall, also known as precipitation, included snow-fall. 10″ of the latter were supposed to give 1″ of rainfall.

The speaker said runoff had two distinct aspects, namely intensity of runoff and volume of runoff. The former covered peak flood discharges as well as mean flood flows for a specific number of hours; the latter covered the volume carried by flood or normal flows during any specific period which might be the duration of a flood, a month or a year. The two aspects of the problem though somewhat inter-related had entirely different methods of approach.

The subject of rainfall runoff had therefore, two distinct sub-heads, one the relationship between rainfall and intensity of runoff and the other between rainfall and volume of runoff.

The speaker said that the authors had dealt with the first sub-head only—the runoff intensity—and that in so far as it affected the design of surface drains, but the method of approach could, with some modifications, be applied to flood flows in rivers and their tributaries.

He said that Mr. Gulhati, the joint author, had worked for the speaker, the peak discharges for one of the highest floods at Bhakra on the Sutlej River, from a study of the record of daily rainfall data available in the Government Gazettes. The result thus obtained was fairly close to the actual, but serious difficulty was encountered in giving true weightage to the rainfall at the various stations as the number of these stations was small and their distribution by no means ideal. Another difficulty the speaker pointed out was, that the records gave the rainfall during the 24 hours of the day but not the actual hours of duration nor its intensity. These latter were rather important for accurate determinations. It appeared to the speaker that the authors' plea for more rain-gauge stations, more evenly spread and for the installation of self-integrating gauges at some of the key stations was, therefore, fully justified.

The speaker informed the House that a good deal of work in this direction had been done in America and had led to the development of the unit-hydrograph method of analysing surface runoff. A unit-hydrograph, he said, might be defined as a hydrograph of surface runoff resulting from rainfall within a unit of time, an hour or a day. According to the speaker the basic hypothesis of the unit-hydrograph could be described as follows :—

1. The unit-hydrograph method was a procedure for determining the peak and other rates of surface runoff from a particular basin, by analogy, from an observed rainfall and the corresponding observed hydrograph of surface runoff from the same given basin.

2. The hypothesis upon which the unit-hydrograph method was based was that in a given drainage basin surface runoff from rainfall occurring in a unit of time would produce hydrographs of approximately equal bases, and the ordinates would vary with the intensity of the net rainfall (net rainfall being rainfall minus infiltration and other losses).

3. The first step in the application of the method to a basin was to find a hydrograph of surface run off due to an isolated one-day (or unit-time) rainfall from an inspection of daily rainfall and runoff records.

The speaker considered it worth while studying this method of analysis on the Punjab catchments.

He said that the flood frequency graphs of Plate VI appeared to him to be wrong. He informed that in the case of Khanki and Marala a flood of nearly 7 lacs occurred in 1903 and again in 1928 and 1929. The frequency of this flood was more like once in 20 or 25 years than 8 to 10 years as shown on the graphs. He considered that any deductions from these graphs would, therefore, be misleading and that it was risky to make deduction from a few isolated values. The subject needed more careful study and analysis.

The speaker said Plate VIII was another instance where almost any value for a flood discharge could be obtained to suit individual fancy. He instanced a drainage area of one square mile. The range of discharge per square mile between the two straight lines was from 1,100 to 4,500 cusecs. For a 1,000 square miles catchment this range was from 50 to 400 cusecs per square mile. In view of this very large range of variation, runoff (intensity) worked out as a function of catchment areas was according to the speaker likely to be very much in error unless that function were derived from the very area concerned or from some adjoining area of identical rainfall distribution and catchment characteristics.

According to the speaker the correct method of working out flood peaks was that explained by the authors earlier in the text, namely from a study of daily rainfalls and their duration and intensity when available.

He said the authors had not dealt with the rainfall runoff volume relationship. He considered it desirable to have this aspect of the subject studied in the greatest possible detail, as it had a vital bearing on the supplies likely to be available in different rivers in different months of the year and during the year as a whole. If some general laws could be established relating rainfall and runoff, he thought much useful information might become available from past records of rainfall as the latter went much farther back than the discharge observations. Similarly he said it would be possible to find out the runoff of streams where no discharges were observed.

The speaker was of the opinion that the commonly accepted concept of runoff (volume) as a percentage of rainfall, was faulty and might be misleading. A sounder concept he said was that the runoff was a residual of rainfall after deduction of losses by evaporation and transpiration. This could be expressed in the form of an equation :

$$R = P - E$$

where R=Runoff in inches over the catchment.
P=Precipitation or rainfall in inches over the catchment.
and E=Evaporation in inches over the catchment.

He said that the annual loss by evaporation, which included losses by evaporation as well as transpiration, depended upon many factors, namely, temperature, humidity, wind movements etc. It however appeared to the speaker, that temperature effect predominated and with suitable allowance would represent all other factors and be a measure of the evaporation loss, and thus the mean monthly temperatures would measure the monthly evaporation losses and the mean annual temperatures, the annual ones. From a study of rainfall, runoff, and temperature data of some 15 catchments in the United States, the relationship between temperatures and evaporation was given by the equations

$$E = \frac{T}{2} + C \text{ for the year}$$

$$E_m = \frac{T}{24} + C' \text{ for the month with due regard to seepage inflow and outfall and falling and melting of snows}$$

where T was the mean annual or mean monthly temperature over the catchment as a whole, in degrees Fahrenheit. In studying the monthly losses in the snow bound part of a catchment, it had been found that the loss was greater than $\frac{T}{24}$ in the months of January and February due to the precipitation in that part occurring in the form of snow which did not appear as runoff till the latter began to melt in March and April. In the latter months the loss would be less than $\frac{T}{24}$ to the extent of the melting of snow which formed an addition to the normal runoff resulting from rainfall in the period concerned. The relevant data for these 15 catchments had been given in the enclosed table.

The speaker said that from this table it would be noticed that the catchment areas ranged from 119,000 to 18·9 square miles, the mean annual temperatures from 61·5 to 35 degrees Fahrenheit and rainfall from 54·6″ to 20·9″, but that the relationship $E = \frac{T}{2} + C$ held every where (see Plate IX). On the other hand, it would be noticed that the percentage ratio of runoff to rainfall varied over these catchments from 6% to 52·9%. On the same catchment, however, the variation in percentage would not be so large. In other words the concept of runoff as percentage of rainfall was according to the speaker definitely faulty and misleading and the more rational concept of runoff as a residual of rainfall after deducting losses by evaporation and transpiration, was the one to be accepted and further explored.

This concept was being tried in the case of the Punjab catchments but the speaker thought that for want of temperature data, the investigation might not make much headway.

The speaker cautioned against using this formula in arid regions where the annual rainfall in inches was less than half the mean annual temperature in degrees Fahrenheit. In such cases he said it would be necessary to make a monthly analysis so that the months during which the precipitation was less than $\frac{T}{24} + C'$, might be considered as non-contributing. This he offered as a possible method of approach, and said that no specific cases had yet been studied.

The above discussion the speaker stated pointed to some important gaps in our data and to the urgent necessity of having these made up by installing more and suitably distributed rain-gauge stations with a reasonable proportion of integrating gauges and more stations for record of temperatures. A knowledge of temperatures was he thought about as important in a study of river supplies as that of rainfall.

The speaker concluded his remarks by saying that the subject of rainfall and runoff was of very great importance and one which could profitably be taken up by the Central Board of Irrigation, as an all India problem.

TABLE SHOWING MEAN ANNUAL RAINFALL, RUNOFF AND TEMPERATURES IN SOME AMERICAN CATCHMENTS.

$$R = P - \frac{T}{2} + C.$$

Sr. No.	Name of River Basin	Catch-ment area in sq. miles	No. of Rain gauge sta-tions	Period of Re-cord years.	Precipi-tation Inches. P	Runoff in inches. R	% $\frac{R}{P}$	Evapora-tion loss. P−R=E	Temp. Fah. T	$\frac{T}{2}$	C= $\frac{T}{2}$ − E
1	Mississippi River above Keokuk, Iowa ..	119,000	227	57	29·51	6·98	23·6	22·53	45·20	22·60	+0·07
2	Red River above Grand Forks, N. Dak ..	25,500	28	53	20·91	1·25	6·0	19·67	39·80	19·90	+0·23
3	Tennessee River Basin above Chattanooga, Tenn ..	21,400	32	54	50·36	24·24	48·2	26·12	55·80	27·90	+1·78
4	Tames River Basin above Cartersville, Va ..	6,240	11	36	40·79	15·59	38·2	25·20	54·90	27·45	+2·25
5	Muskingum River Basin above Dresdon, Ohio ..	5,828	?	8	39·70	13·02	32·9	26·68	49·5	24·75	−1·93
6	Upper Hudson River ..	4,500	?	14	44·5	23·5	52.9	21·0	42·0	21·00	0·00
7	Merrimack River Basin above Lawrence, Mass ..	4,461	33	55	41·63	20·13	48·4	21·50	45·6	22·80	+1·3
8	Neosho River Basin above Iola, Kana ..	3,800	19	39	33·57	4·12	12·25	29·45	55·6	..	..
				17	32·31	4·12	12·4	28·19	56·1	28·05	−0·14
9	Chettahoochee River Basin above West Point, Ga ..	3,551	13	38	54·59	22·32	40·9	32·27	61·5	30·75	−1·52
10	Miami Valley above Dayton, Ohio ..	2,525	?	25	38·07	11·87	31·2	26·2	52·7	26·35	+0·15
11	Upper Genessee River ..	1,070	?	9	40·20	14·2	35·3	26·00	45·45	22·73	−3·27
12	Wagon Wheel Gap on the Upper Rio Grande, above San Luis Valley, Colo ..	1,000	?	7	21·0	6·08	28·8	14·92	35·00	17·50	+2·58
13	Pomperaug Basin, Connecticut State ..	89	?	4	44·48	19·53	44·0	24·95	48·8	24·4	−0·55
14	Sudbury River ..	77	?	21	45·80	23·5	51·5	22·3	47·80	23·90	+1·60
15	Lake Cochituate ..	18·9	?	33	47·5	20·50	43·2	26·6	47·50	23·75	−2·85

Dr. J. K. Malhotra congratulated the authors on what he considered their new and very able approach to the old problem of rainfall and runoff.

He said that on page 133 the authors had used in para 4 the adjectives "high" and "moderate" in relation to intensity. It would be useful if they could define the ranges of "high," "moderate," and "low" intensities, and also state if these ranges should be taken to be the same for different stations, *e.g.* Cherrapunji and Lahore.

Referring to PLATE II of the paper, the speaker said that the maximum intensity decreased with the period of observation, and reading from the smooth curve drawn by the authors the following values were obtained :

Period (in hours).			*Intensity (Inches per hour).*
·50	..	..	4·3″
1·00	..	..	2·2″
1·50	..	..	1·7″
2·00	..	..	1·3″
3·00	..	..	·9″
4·00	..	..	·7″
5·00	..	..	·6″

The relation for the greater part of the curve the speaker described by the equation

$$I = \cdot 25 + \frac{2}{t}$$

He said: "The total rainfall, which equals it, is therefore given by $2 + \cdot 25T$. This would indicate that the longer the duration of a shower of maximum intensity, the bigger the total rainfall, and this fact is brought out in PLATE III.

"By omitting the last two points in PLATE II, however, the intensity time smoothing curve can be written as

$$\mathrm{I} = \frac{2\cdot 5}{T}$$

in which case the curve in PLATE III would reduce to a horizontal straight line. As it is conceivable that a smoothing curve could be so drawn as to make $I\ t$ even decrease as t increases, I would like to express some doubt as to the general applicability of the graph in PLATE III."

The authors' statement on p. 135, that the curve of one of the storms at Lahore conformed very well with the graph obtained for Lower Jhelum Canal did not really establish the utility of the curve unless it was shown that the storms in the two areas had similar characteristics.

The speaker said that the more appropriate word to use for lines of equal rainfall was "isohyetals" and not "hyetographs." They spoke of "isothermal" lines of "isobars" but not of "thermographs" or "barographs."

The speaker then went on to say that the authors' recommendation in regard to spacing of rainfall stations as given in para. 8 of the paper did not lay enough stress on the range of variation of rainfall in the area. While he would be the first to admit that equality of average annual rainfall over a number of years did not necessarily imply similarity of distribution from year to year or from station to station, it seemed that the spacing should have some reference to the range of variation. For example if the average annual rainfall varied from about 40″ at one end of the area to 10″ at the other, the spacing must be closer than if the variation was from 40″ to 35″.

In January 1940, the speaker at the request of the Drainage Circle made some suggestions for the location of rain-gauges in Bist Doab. The following extracts from the note then prepared were likely to be of some interest to the authors.

CRITERIA FOR LOCATION OF RAIN-GAUGES

"The location of rain-gauges in any area should theoretically have reference both to the total area commanded and to the range of variation of rainfall.

1. *Total area commanded.*—The area of the tract as roughly estimated from the index plan, is about 3,600 square miles. There are at present only 9 R. G. stations in the area, *i.e.* about 1 station to 400 square miles. This may be compared with the following densities in some of the irrigated areas. (The values in columns 2 and 3 are taken from Irrigation Statistics 1936-37).

Canal System	G.C.A. (Sq. miles)	No. of Stations.	Density (Area per station).
1. W. J. C. ..	4280	49	87
2. S. C. ..	3750	23	163
3. U. B. D. C. ..	2440	32	76
4. L. B. D. C. ..	2810	23	122
5. U. C. C. ..	2400	16	150
6. L. C. C. ..	5640	46	123
7. U. J. C. ..	840	23	37
8. L. J. C. ..	2090	16	131 Average 110

It would, therefore, be sufficient to adopt a density of 1 station per hundred square miles for the Bist Doab. This would give 36 stations.

2. *Range of variation of rainfall.*—The rainfall in this tract has a range of variation of about 15″. The rainfall average at each of the existing nine stations is shown below: (The values are taken from those supplied by " The Metereological Reporter to the Government of India and Director General of Observations.")

Serial No.	Station.	Total Average rainfall in a year.	No. of years over which data extend.
1	Una ..	36·22	55
2	Hoshiarpur ..	35·51	54
3	Dasuya ..	32·46	55
4	Garh Shankar ..	30·58	55
5	Nawanshahr ..	27·90	55
6	Jullundur ..	26·96	54
7	Phillaur ..	24·16	55
8	Tanda ..	22·62	59
9	Nakodar ..	22·47	55

The following table shows the number of stations per unit of range of rainfall for other Doabs.

Canal System	*Average Annual Rainfall.*			No. of R. G. Stations.	No. of Stations per inch.	
	Max.	Min.	Range.			
W. J. C. ..	30·7	9·6	21·1	49	2·3	
S. C. ..	23·0	9·5	13·5	23	1·7	
U. B. D. C. ..	50·2	15·4	34·8	32	1·0	Whole Doab 1.3
L. B. D. C. ..	14·5	6·2	8·3	23	2·8	
U. C. C. ..	35·2*	14·2	21·0*	15	·7*	Whole Doab 2.3
L. C. C. ..	23·0	8·9	14·1	46	3·3	
U. J. C. ..	35·1†	15·7†	19·4	23	1·2	Whole Doab 1·4
L. J. C. ..	23·3	7·3	16·0	16	1·0	
Average ..	..	..	..	..	1·8	

If a range of 15 inches is adopted for the Bist Doab and two stations are allowed for each inch of variation it would be necessary to have 30 stations.

*Omitting Riasi, which is not in irrigated area.

†Figures for 1936-37 only.

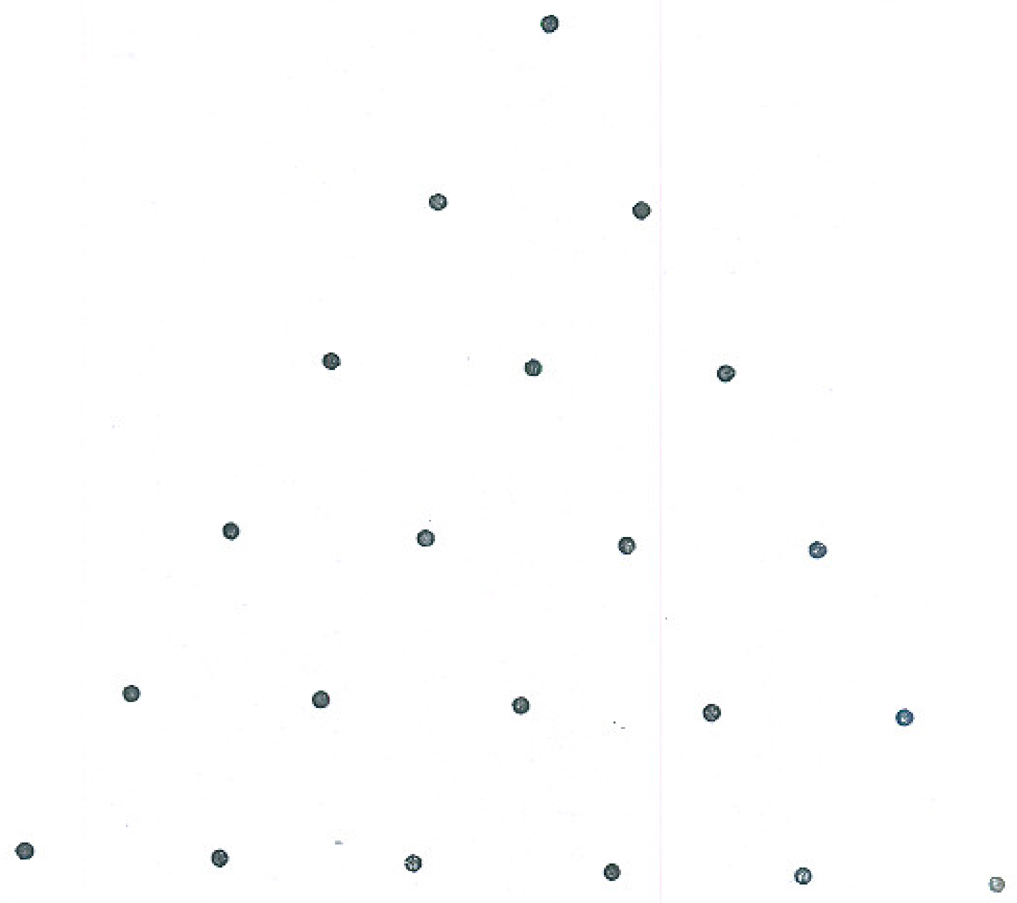
SUGGESTIONS FOR LOCATION OF RAIN-GAUGES IN BIST DOAB

As, however the establishment of R. G. stations is a costly affair, and their supervision, in the absence of the communications usually associated with a canal system, likely to be somewhat difficult, it is proposed that only 12 additional stations should be established, besides the nine already under regular observation.

The criteria for selection have been, in addition to those given in the first paragraph the accessibility from railway and the filling up of areas not already represented.

In case it is found practicable to put R. G. Stations at points removed from railway stations, it would be advisable to have them put in the following staggered pyramid pattern, keeping the distance between neighbouring units about fifteen miles, as shown in Fig. 15.

FIG. 14



This will mean 21 R. G. stations, from which the existing eight can be excluded by cutting out the points nearest to them, leaving 13 new R. G.'s to be established."

In regard to the method outlined in para. 9 of part II the speaker quoted from a recent paper* in the proceedings of the American Society of Civil Engineers. The whole of this paper, which appeared in the issue for November 1940, according to the speaker would repay careful study, and he quoted :—

"Although by this method more storm experiences may be obtained than in a record for a single station, it obviously cannot be assumed that more actual years of time are being sampled by this expedient. A record from 10,000 rain-gauges operating on an area for one year cannot replace 10,000 actual years of record for one station although both records could conceivably include the same number of storm experiences. The reliability of an average frequency computed from these two 10,000-station-year records might be the same, but only if each rainstorm of given intensity affected only one station.

Regardless of how many station-years of record are used, there will always be a certain degree of unreliability in the frequency determinations simply because the actual years of record are not sufficient to sample all the possible annual variations in the rainfall characteristics. If every year had the same characteristics and if there were no abnormally wet or abnormally dry years, then, of course, any one year of record would give as reliable values as any other year. Furthermore, if there are cyclic or secular changes in rainfall, the frequencies from data obtained during a part of a cycle or period may not be applicable to other parts of the cycle. The Miami engineers recognised that the station-year method was valid only if "there are no permanent or cyclic climatic changes affecting the occurrence of high rates of rainfall."† This might have been expressed in another way by saying that there will be a high degree of unreliability in the frequency values if there are cyclic or permanent changes in the occurrences of high rates of rainfall."

The speaker further stated that the writer of the paper referred to had also given a statistical method, for finding the reliability of the frequency. Effectively it meant the fixing of a range for the frequencies and not of absolute values as was done by the authors. Two other curves according to the speaker would therefore need to be drawn in PLATE IV one on each side of the curve drawn by the authors, and the band between these accepted as the range of frequencies.

* "Reliability of station year rainfall-frequency determinations" by Katharine-clarke-Hafstad, proceedings, Am. Soc. C.E., Vol. 66, (1940), p.p. 1603-1622.

† "Storm Rainfall of Eastern United Statee," Miamy Conservancy District, Eng. Staff, *Technical Reports*, Pt. 5, Revised Edition, 1936, Dayton, Ohio, p. 67.

The speaker opined that the transpiration losses given on page 143 were very approximate figures and could be accepted only as indicators of the order of magnitude of the losses. He quoted from the original paper.

"Figures are not available for crops grown in the Punjab but if we take Pusa records as a basis and add 25 per cent. for the drier climate of the Punjab, figures are obtained which will give some indication of the water which may be dealt with by crops in the Punjab."

The speaker considered that transpiration was, however, not a constant quantity from year to year. Maximov ('The plant in relation to water,' Allen and Unwin Ltd., 1929, p. 313) states 'The transpiration co-efficients of plants which is an expression of their water requirement during the period of growth is an extremely variable figure fluctuating markedly from year to year according to the climatic conditions obtaining during the period of growth.' It depended on humidity, temperature, soil moisture, presence of fertilizers and light.

Referring to the changes in runoff with changes in the topography of the catchment, the speaker remarked that the authors had discussed the effect of the shape of the catchment on page 146 and also reverted to this subject in para. 2 of Chapter VI.

Where the catchment is fan-shaped Mr. Inglis had given the following formula for the maximum flood discharge.

$$\text{Runoff (in cusecs)} = \frac{7000\ A}{\sqrt{A+4}}$$

During the discussion on 'The collection and study of statistical data pertaining to flood control,' at the Eleventh Annual Meeting of the Central Board of Irrigation* Mr. Inglis had stated that 'it fitted all catchments in India, provided the catchments were fan-shaped and not elongated.' He had also stated that 'in the case of exceptionally high floods runoff was not appreciably affected by the physical nature of the catchment, because the soil was then completely saturated.' The authors might well try this formula against the data given on PLATE VIII of their paper.

The effect of vegetable cover was shown by the experiments carried out at Nurpur by the Forest Department. The results for

* Proceedings of the 11th Annual Meeting of the Board, held at Simla, in July 1940.

July 1937—December 1938 as adapted from the Report of the Irrigation Research Institute for the year ending April 1939, were:

SUMMARY OF THE RESULTS OF RUNOFF EXPERIMENTS AT NURPUR.

(July 1937—December 1938).

PERCENTAGE RUNOFF.

Period	Total rain (inches)	*Mean percentage runoff.*		
		Trays 1 & 2	Trays 3 & 4	Trays 5 & 6
1937—				
July—September ..	37·9	20·6	16·3	39·8
October—December	9·7	16·9	3·5	39·4
1938—				
January—March ..	10·9	23·9	7·1	46·7
April—June ..	9·0	14·4	7·3	51·4
July—September ..	30·3	11·7	8·8	61·2
October—December	·7	..	3·1	13·5
Total ..	98·5	17·1	10·8	0.84

According to the speaker these results were admittedly from small scale experiments and were qualitative in nature but they showed that the bare area allowed a much bigger runoff than areas covered by grass or grass and scrub.

The speaker had no comments to offer on Chapters IV and V, but he thought that it would have added to the value of the paper if the methods and results developed therein had been applied to an actual case. The authors had given figures for intensities over the Lower Jhelum Canal area in PLATE II. It would have been of interest to know the values of the runoff recorded by some of the drains in this area during the period covered by the rainfall observations.

The speaker in his concluding remarks said that the need for collecting further data and for its analysis was apparent. The second recommendation under (*i*) on page 171 he said was very reasonable and would be a great advance, till such time as integrating rain-gauges could be installed.

Mr. G. R. Sawhney thanked the joint authors for the immense amount of work put in by them to evolve these formulæ and hydrographs for calculating the all important rainfall runoff.

He however considered it a pity that their calculations were mostly based on assumptions, expectations and not too reliable a data and therefore these formulæ when applied for designing drains in different parts of this country were very likely to give vastly varying and even disappointing results.

He said nothing in this world was so fatal to the development of the intellectual powers as what are commonly called expectations.

The introduction of integrating rain-gauges he said was undoubtedly the only thing to do, and until this was done their readings were likely to give them a very rough estimate of the runoff. The indirect methods would at the very most be a very poor apology.

To the speaker the authors seemed to have based their calculations on the intensities of rainfall irregularly observed at odd places and by applying law of averages which may or may not suit the various localities.

The authors had referred to some very plausible conclusions arrived at by various famous scientists of Europe and America, but the geographical conditions and methods of collection of data of this country were poles asunder from those of other countries. The speaker remarked that very correct conclusions which were applicable in those continents should not in a hurry be made the basis for calculating runoff, till some really reliable data for different tracts had been collected.

He suggested that for spacing of rain-gauges the country should be divided into separate zones and then number of stations fixed for each zone as from a mere layman's experience it would be quite evident that there existed a marked difference in annual rainfall in different tracts of this very Province, depending on their geographical position and the direction of prevailing winds. He recommended that the gauges should therefore be fixed at shorter distances in zones in which rainfall was heavy and at a little longer distances where rainfall was less. In the speaker's opinion the effect of cultivation on the runoff and the supposition of the canal irrigated area being considered as equivalent to 10% of banjar area was on the very low side, and drains designed on this basis were sure to lead to trouble somewhere or another. According to the speaker in such areas the drains had in some cases to take away even the canal water besides the rain-water whenever there was a continuous heavy rainfall and the canal not closed at head.

He hoped that things would become very easy when engineers would pay proper attention to observing and recording intensities carefully and would be able to judge and determine the all important Inlet Time, and not till then.

In conclusion the speaker said that whether it was a question of combination of hydrographs, determination of Inlet Time or calculation of absorption losses the authors had taken too much for granted and unless and until they could persuade the Government to have integrating gauges fixed in suitable places and make proper arrangements for having all the data properly recorded, they would only be building castles in the air. He commended the authors for their persistent endeavours and hoped that they would all gain thereby.

Mr. Kanwar Sain congratulated the authors of the paper for their originality of the analysis of the problem and for the clarity with which they had put forward their subject. Before coming to closer grips on practical issues, he would point out that the authors did not carry their analysis far enough to be useful to such Engineers to whom it was of greater importance to know what the total annual runoff would be rather than the maximum runoff on any one day.

He referred to page 142 where the authors quoted Buckley to support their claim that evaporation losses in India were of the order of 1/100 inch per hour and further to where they quoted that in U. S. A. evaporation losses observed in 1887-88 in June and July were only 5·5 and 6·7 inches respectively.

These figures, he said, were very much on the low side for the plains of the Punjab.

The speaker said that actual observations in India were scanty. In 1934, Messrs. Raman and Satakopan of the Meteorological Department calculated evaporation for a large number of stations in India from other meteorological factors. He considered a detailed description of their method outside the scope of the present discussion. Their figures for Lahore and Multan were :—

		Lahore	*Multan*
May	..	13·30″	13·24″
June	..	13·11″	14·76″
Annual	..	73·64″	86·11″

These he considered big losses and appreciably more than the mean rainfall at these places. They did not include anything for transpiration by plants. This proved the contention previously put forward by him that most of the rainfall in the Western and Central Punjab plains was finally dealt with by evaporation, although the runoff from an individual storm was more affected by the storage power of the soil on which the rain fell.

He said, "Authors have developed on Plate II a curve of maximum intensity and state on page 134 that there is little likelihood of such graphs showing any marked variation in the various districts of the Punjab.

"According to authors' own analysis, the daily rainfall as recorded by the Symen Rain-Gauges can be of little use for the design of drains. I shall prove this by a reference to table 5 on page 145.

"On good soil, absorption loss is 0·5″ per hour. This means 12″ in 24 hours. Even for Kalrathi soil this comes to about 5 to 7 inches. How many stations in the Punjab record a daily rainfall coming up to these figures except for deluges such as at Rohtak? If these premises are accepted what is the need of establishing more rain-gauge stations? To get more information regarding the hydrographs of storms about a dozen Integrating Rain-Gauges are all that appear to be called for. These Integrating Rain-Gauge stations may be placed at representative places in the Punjab."

Continuing the speaker said that the authors had developed a much-needed principle that would effect a great deal of improvement on our present knowledge of the design of drains but they had not taken any trouble to demonstrate it by comparing their results with actual observations made on drains. It would be only after they did this comparison that the real use of the principle enunciated by them would be proved.

Certain assumptions made in the paper would lead one to think that the paper was more of academic interest. Referring to page 158 of the paper, where intensity of normal flood had been worked out in the cases of Mangla, Marala and Khanki, the speaker said that the river discharge at these places depended on the rainfall in their hill catchment areas and it might safely be stated that there was hardly much analogy between the variations in the rainfalls in Hills and the Plains.

He gave the following information :—

Rohtak—

From 17th to 18th	3·0″
From 18th to 19th	23·24″
	26·24″
Mean rainfall Annual (mean of 70 years) ..	19·44″
Rainfall in wettest year ..	55·17″
Rainfall in driest year ..	2·70″

The exact size of a drain would perhaps be more governed by the finances available and the purpose for which the storm water drain was required. Any drain he said would dispose of the runoff; the question being only of time. A large drain would get rid of the runoff in a short time and small drain would take a longer time to do the same. There was always ample storage capacity in the Punjab Plains. The question was what was the maximum time you could allow any volume of water to stand on the ground after a storm of maximum intensity without doing any danger.

According to the speaker the reply to this question would be different for different localities and the size of the drain in any locality would depend to a great extent on a reply to this question. The speaker stated that in September, 1933, when Rohtak was literally flooded by a deluge, the only effective way in which the great volume of water was disposed of was by absorption in the soil as it could not be drained off. This did take a long time resulting in inconvenience and damage to the town.

The speaker considered that the authors had disposed of "the storage provided by the catchment" in somewhat contemptuous manner. In his opinion this was an important factor, and the drain itself may provide storage which may appreciably affect the design of the drain section and the masonry works on the drain.

In conclusion the speaker wanted to add to the Bibliography of the subject by referring the authors to an excellent paper that had just come to his hands. He referred to Paper No. 2057 of the American Society of Civil Engineers published in the transactions for 1940. The heading of the paper was given as "Analysis of Runoff Characteristics, by Otto H. Meyer."

Mr. S. L. Kumar said that Messrs. Gulhati and Khangār had done a great service to the profession in bringing to the forefront the importance of the problem of runoff from catchments. They had also brought to the notice of the authorities the urgent need of having a very much larger number of rain-gauges and of the installation of a number of Integrating Rain-Gauges distributed all over the country. Without these the type of storms and their frequency could not be determined. No theoretical investigation could be of any value unless reliable basic data regarding the amount of rainfall was available. On two occasions the speaker said he had realised his helplessness and that of his colleagues for want of reliable information regarding runoff figures of certain catchments in the Punjab.

When the ill-fated Lyallpur and Jaranwala railway line was being constructed, the alignment crossed what looked like kutcha country roads about 100 ft. or more wide. They were however surprised when they were asked to bridge these roads, which, as stated by the Irrigation authorities, were really drains. When told that local enquiries had revealed complete absence of the flood water having run in the past over these drains for several years and asked further why they wanted the whole width to be bridged, the Irrigation authorities said that they had no information on the probable runoff of the future drains but it was necessary to provide bridges as they were going to construct such drains very soon. In order to economise, it was decided by the railway to provide armoured dips at these sites.

The speaker went on that a few years back the North Western Railway wanted to replace the existing dips on Wazirabad-Khanewal section. It was found that no reliable records of flood that had passed over these dips existed. The Irrigation Department could give no useful information. For want of the requisite information combined with other reasons the project was ultimately shelved.

From the above two instances, the speaker concluded that it was clear how reliable data on the amount of runoff to be expected from the irrigated plains of Northern India could be of great use as it would enable engineers to decide on the water-way required on the basis of scientific methods and not by the trial and error method used in the past.

Mr. T. A. W. Foy said that he wished to confine his remark on Messrs. Khangar and Gulhati's interesting paper to pointing out the extreme danger of the graph of rainfall of maximum intensity as plotted at Plate III. He was aware of at least 3 storms in which the intensities seriously exceeded the values given by the graphs. One and probably the worst for all time was the Rohtak 1933 storm when the total rainfall exceeded 23 inches in 24 hours; the hourly intensities of this storm, he believed, were recorded by Rai Bahadur Lala Kanwar Sain and reported in his Congress paper No. 194 of 1936.

The speaker further stated that in Bikaner there was a storm in 1933 of approximately 12 inches in 24 hours and again in 1936 of 18 inches in 48 hours, and for both of these storms hourly records were obtainable. He concluded by saying that at the other end of the scale, intensities of 3 inches in the first hour are by no means uncommon. For design purposes this graph, he said, needed recasting.

CORRESPONDENCE

Mr. C. C. Inglis referred to the following in Chapter VI, pp. 165-6, of the paper :—

"To determine the exact law as to how the discharges from catchments under similar conditions would vary with the area of the catchment, a very large number of observed runoff for different sized catchments must be available. *Little record is, however, available in India and it is only possible to fall back upon the work done in other countries.*

"On Plate VIII the data collected in America has been plotted on log paper. It will be seen that practically all the points lie between two parallel lines which satisfy the equation

$$Q \propto A^{0 \cdot 65} \quad "$$

As long ago as 1930, a Government of Bombay Technical Paper (No. 30) was published, entitled "A critical study of runoff and floods of catchments of the Bombay Presidency," and that in this a large amount of Indian data was shown in Plate XXXVI indicating a maximum "Fan catchment formula" of

$$Q_{max.} = 7{,}000 \sqrt{A}$$

Since then, the writer stated that much additional Indian data had been collected and was shown in Plate X. This additional data confirmed that maximum flood runoff was proportional to $\sqrt{A}$ and not $A^{0 \cdot 65}$, as had been stated by the authors; but the formula had been slightly modified to $Q_{max.} = \frac{7{,}000\ A}{\sqrt{A+4}}$; $Q_{max.} = \frac{7{,}000}{\sqrt{A+}}$ to make the "Fan catchment" formula applicable to small as well as large catchments.

The writer stated that in elongated catchments the form of runoff formula was no longer exponential, except for small catchments, and the normal elongated catchment formula for the Bombay Deccan was of a form

$$Q_{max.} = 7,000 \sqrt{A} - 240\,(A-100)\,;$$

and the maximum discharge actually decreased with increase of catchment above 80 sq. miles, up to the point where a tributary stream joined it.

Then referring to American data, he wrote:

"The authors have shown in Plate VIII data published in Engineering News Record of November 25th, 1937. I would, however, call attention to Plate XI which accompanied a letter addressed by Mr. Inglis to Mr. J. Gutmann in the Engineering News Record of July 8th, 1937, which was published as Figure 15 in Bombay Public Works Department Technical Paper No. 58: 'Summary of the Annual Report of Irrigation Research Division, at the Lake Fife Hydrodynamic Research Station, near Poona.' On this, the Authors' curve has been added, to show that it is utterly wrong in form and only seemed to apply in their Plate VIII, because the data was for a restricted range.

"As regards Dr. Malhotra's question: The statement made in the Central Board of Irrigation Report on "Discussions at the 10th Annual Meeting of the Research Committee on the subject 'the collection and study of statistical data pertaining to River Flood Control'" in which the Writer is quoted as below:

"In the case of exceptionally high floods runoff was not appreciably affected by the physical nature of the catchment, because the soil was then completely saturated.

"This does not, of course, mean that the flood runoff from all 'fan catchments' of equal area is the same, as Mr. Inglis has repeatedly explained.

"Thus, in the Southern States of the U. S. A. extraordinary floods occur—*vide* 1,500 cusecs/sq. mile for a 400 mile catchment for which the Inglis formula gives only 350 cusecs/sq. mile. Fortunately, the conditions which lead to such floods in Texas do not occur in India.

"There are also cases, as in Baluchistan, where floods in recent years have never approached $7{,}000\sqrt{A}$ —. No general formula can cover such cases; but what is clear is that size of catchment is the dominant factor, the maximum flood runoff varying approximately as $\sqrt{A}$; and in India, other factors are generally relatively unimportant. As more data becomes available, however, we will be able to evaluate the modifying effects of other factors."

Against one widely-held belief, the writer considered a warning was necessary: Annual rainfall and maximum floods were not linked; and peak floods were often greater from a catchment with a low annual rainfall than from a Ghat catchment with 200″ annual rainfall.

He wrote that although there were many other points in the paper with which he would like to deal if he could spare time to do so, but he would refer the Authors and readers to additional useful information on the subject contained in Bombay P. W. D. Technical Paper 30. He would, particularly, call attention to Plate No. XC of that paper, reproduced as Plate XII. This showed how, in an area where conditions were similar, a simple approximate relation could be worked out between annual rainfall and runoff. The formula

$$\text{Runoff} = 0{\cdot}85\ (\text{Rainfall} - 12'')$$

gave a useful approximation and was easy to memorise.

He would also call attention to Paper No. 2057 of the American Society of Civil Engineers, published in November 1938 Proceedings, entitled "Analysis of Runoff Characteristics" by Otto H. Mayer and the interesting discussion thereon.

Finally, the writer drew the authors' attention to the fact that in India there was an excellent Information Bureau and Library, run by the Secretary, Central Board of Irrigation, Simla, who should have been consulted. Had this been done the Bibliography would have been fuller and the statement "Little record is available in India" omitted.

Replying to the discussion, *Mr. Gulhati* thanked Mr. Roy for his remarks. The author was glad to learn that steps were already being taken to increase the number of rain-gauge stations in the Chaj and Rechna Doabs. He agreed with Mr. Roy that table V as given in the paper was only indicative of the value of absorption losses and that a large number of systematic observations of such losses were required to be carried out all over the Province.

Mr. Roy had asked as to why it had been recommended that capacities of drains should be based on intensities likely to be obtained once in 3 years and had given some data showing the disparity in the observed maximum discharges of the last 3 years with the previously recorded maximums. In reply Mr. Gulhati referred to the remarks in paragraph 1 of Chapter V in which it had been stated that the capacity of a drain would depend on the extent of the development of the area served by it and that the additional cost of a more expensive scheme had to be justified by the occasional damage likely to occur from a drain of smaller capacity. The 3 years' basis had been recommended only as a tentative suggestion and if in any particular area this capacity was not found to be enough this criterion would certainly have to be revised. The author was, however, of the opinion that in irrigated tracts the damage from drains designed with a 3 years' frequency was not likely to be much. As regards the analogy between drains and rivers the author stated that rivers were essentially drains and although different coefficients or indices might apply the essential principles were the same.

In reply to Rai Bahadur A. N. Khosla the author stated that the unit-hydrograph method could be applied to a catchment in which the conditions of vegetable cover did not appreciably vary, or to those catchments which were so large that small variations did not matter. To be able to use this method it was necessary to have runoff data for unit periods for a known rainfall. In the absence of this information this method could not be applied. The author agreed with Rai Bahadur Khosla that the shape of the flood-frequency graph on Plate VI was not what it should be from theoretical considerations. Only 20 years' records, however, existed and the available data could best be represented by the graph drawn by the authors. If and when further data was collected it would be possible to alter the shape of the curve. It would, however, be seen that the lower part of the curve would not alter and it was only that part which had been made use of in the paper under discussion.

Continuing Mr. Gulhati thanked Rai Bahadur A. N. Khosla for the very valuable contribution made by the latter to the volume study of runoff. He agreed that the true concept of runoff was rainfall minus absorption as would appear from a study of Chapter IV of the paper. There were however certain limitations to the use of the formula R = P-E. It was applicable to mean results obtained over long periods. The formula pre-supposed that the infiltration into subsoil during one part of the year would appear as runoff during some subsequent period within the same year or soon after. This could only be true if subsoil water table had assumed equilibrium and so long as the water table was rising or falling this formula could not be applied. It could also only be used in volume studies and not studies of intensity of runoff.

In reply to Dr. J. K. Malhotra the author stated that the adjectives high and moderate on page 33 had been used in their general sense. He could, however, refer Dr. Malhotra to the classification of intensities of rainfall by Hinrich*

Type	*Amount*	*Degree*
0	.01 to 0.1	.. Sprinkles of insignificant rain.
	Useful for grass, grain and corn	
1	.1 to .2	.. Showers.
2	.2 to .4	.. Light rain.
3	.4 to .8	.. Soaking rain.
	Excessive or Damaging rains.	
4	.8 to 1.6	.. Washing rains.
5	1.6 to 3.2	.. Flooding rains.
6	3.2 and up	.. Torrential rains.

* D. W. Mead, "Hydrology", page 239.

Continuing the author stated that Dr. Malhotra's reasons for determining the applicability of the graph in plate III were not scientific. An imperical graph could not be improved upon by ignoring part of the observed data. The proper thing was to collect more data and then to modify the previously obtained relation if necessary. The very fact that the curve of one of the storms at Lahore conformed with the graph obtained on plate III showed that the storms in the two areas had similar characteristics. Of course a very large amount of data was required to be able to definitely say so.

As regards transpiration losses these would appear to mainly depend on temperature as other factors, *viz.* humidity, etc., were really dependent on it (temperature).

With regard to the concluding part of Dr. Malhotra's criticism the author stated that nobody would have been happier than himself if it were possible to apply the methods and results obtained in Chapters IV and V to available actual cases. Unfortunately, rain-gauge stations were spaced too far apart and detailed runoff figures were not available. To this was added the difficulty that good storms occurred only once in 3 or 4 years. If, however, further data was collected on the lines indicated in this paper and analysed, it would certainly add considerably to the knowledge on the subject.

In reply to Mr. Sawhney the author stated that they had not applied the law of averages but had tried to base their results on maximum values. Mr. Sawhney's fears regarding taking canal irrigated area as equal to 10% of equivalent banjar area appeared to be based on lack of knowledge of the working of drains. Of course it was never intended to design drains capable of taking the full supply dischages of canals. Mr. Sawhney did not appear to have read the paper carefully as the authors had nowhere accepted anything which was not based on facts.

In reply to Rai Bahadur Kanwar Sain the author stated that as explained in paragraph 1 of Chapter V it was necessary to determine for each area the type of storms that precipitated on it and the frequency with which such storms occurred. It was only then that the correct hydrograph for runoff for the particular area could be determined. It was only for the period until such data could be collected that the authors advocated the indirect method of determining normal runoffs from a study of the maximum possible runoffs. With regard to the storage provided by a catchment each case had to be considered on its merits and no general rules could be laid down.

The author thanked Mr. Kumar for stressing on the importance of the problem to railway engineers.

In reply to Mr. Foy the author stated that in dealing with problems like rainfall there were two kinds of maximums—one might be termed a normal maximum which occurred frequently enough to be taken notice of and the other a super-maximum or what Rai Bahadur

Kanwar Sain had called a deluge which occurred at long intervals of say, once in 100 years. It would be appreciated that it was not practicable to legislate for such deluges.

In reply to the written discussion of Mr. Inglis the author wrote that a bibliography on the subject had been obtained from the Central Board of Irrigation but as from its name Mr. Inglis' paper appeared to refer to floods and runoff from a particular locality only, *viz.* Bombay Deccan, where conditions were widely different from those in the plains of Northern India, the book was not referred to by the authors. Mr. Inglis had quoted two formulæ

$$Q = \frac{7{,}000A}{\sqrt{A+4}} \text{ for fan shaped catchments}$$

and $Q = 7{,}000\sqrt{A} - 240\,(A\text{-}100)$ for elongated catchments of 100 to 600 square miles.

The following discharges for different sized catchments could be worked out from these formulæ.

Area in sq. miles	Discharge in cusecs	
	Fan shaped catchments	Elongated catchments
1	3,130 cusecs	
10	18,710 ,,	
50	47,630 ,,	
100	68,640 ,,	
200	98,020 ,,	75,220 cusecs
500	155,900 ,,	60,500 ,,
1,000	221,000 ,,	

Those acquainted with runoffs from flat irrigated areas would readily appreciate that Mr. Inglis' formulæ were as remotely applicable to such cases as those obtained from American or English data. Mr. Inglis' formulæ did not account for the variation in the topography of catchments and a study of the remarks on page 146 of this paper would show that the effect of cultivation alone was far too important to be ignored.

The author further stated that Mr. Inglis had misquoted the authors on Plate XI. The authors had nowhere stated that the maximum discharge would vary as $A^{\frac{2}{3}}$. In paragraph 2 of Chapter VI of the paper they had stated that this relation appeared to apply to the data shown on Plate VIII but in the same paragraph they had stated that it would not be right to accept this value of the index as of general application. The authors would like to refer Mr. Inglis to their general formula

$$Q = 161 A_{o} \frac{Z \cdot F}{T} \left(\frac{A}{A_{o}}\right)^{m}$$

as given on page 166 of this paper. Mr. Inglis like many other scientists appeared to have tacitly assumed

$$A_{o} = 1 \text{ square mile}$$

Mr. Inglis had stated that no general formula could cover all cases but what appeared to be clear to him was—

(*a*) that the size of catchment was the dominant factor,

(*b*) maximum flood runoff varied approximately as $\sqrt{A}$,

and (*c*) in India other factors were generally unimportant.

With regard to these assertions the author stated :

(*a*) This would be so after the area of the catchment had been reduced to the equivalent effective *banjar* area as described in para. 4 (*vi*) and (*vii*) of chapter V of the paper under discussion.

(*b*) This would apply only to the Bombay Deccan catchment or to other catchments having similar slopes and subject to similar rainfall.

(*c*) If by India Mr. Inglis meant "Bombay Deccan" the statement might be correct, but a study of this paper would show that the statement could not be true when applied to the very widely different conditions existing in a vast country like India.

In conclusion the author requested Mr. Inglis to read this paper carefully as it attacked the problem from an entirely different angle from that of Paper No. 30 by Mr. Inglis.

FIG. 14
PAPER NO. 245

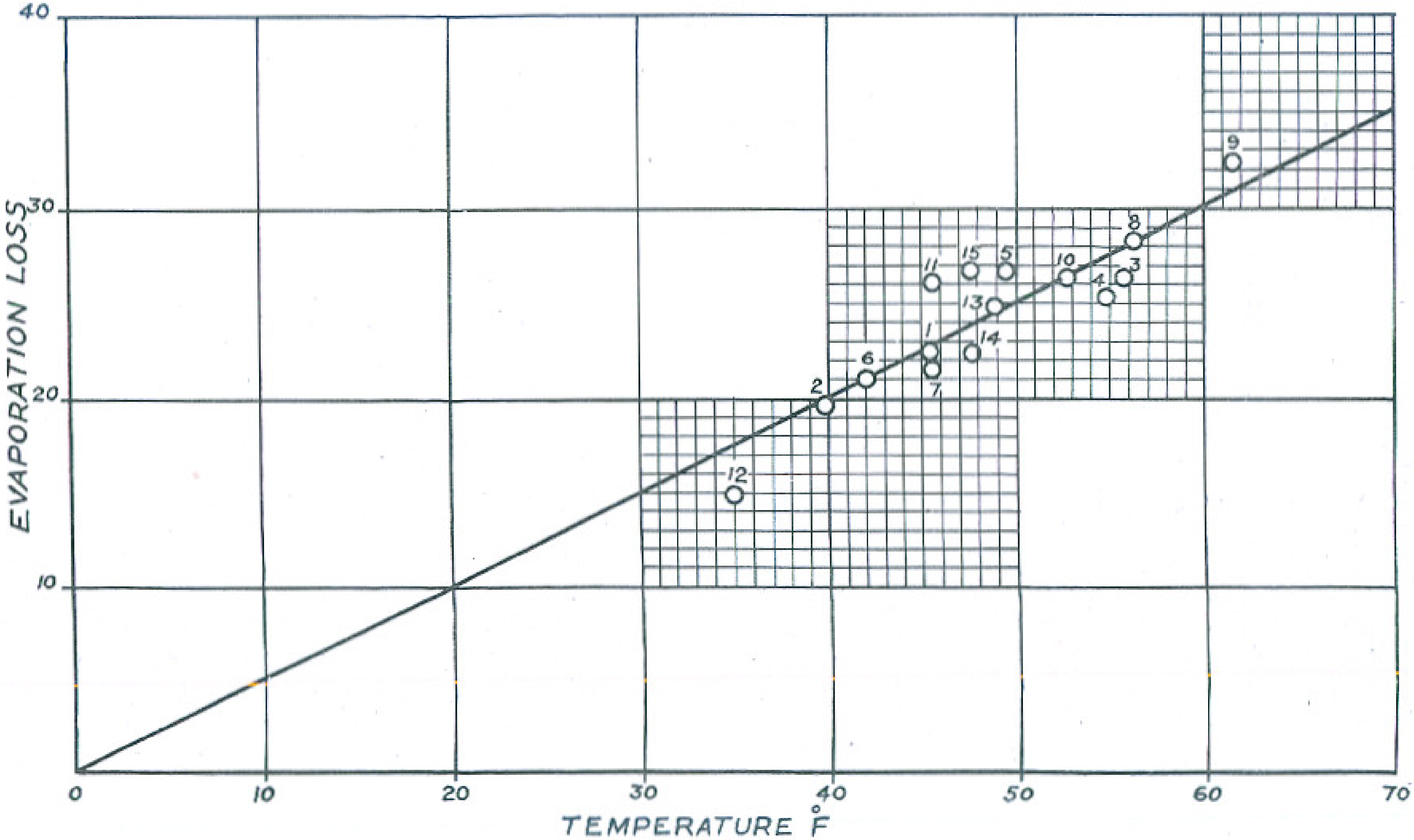
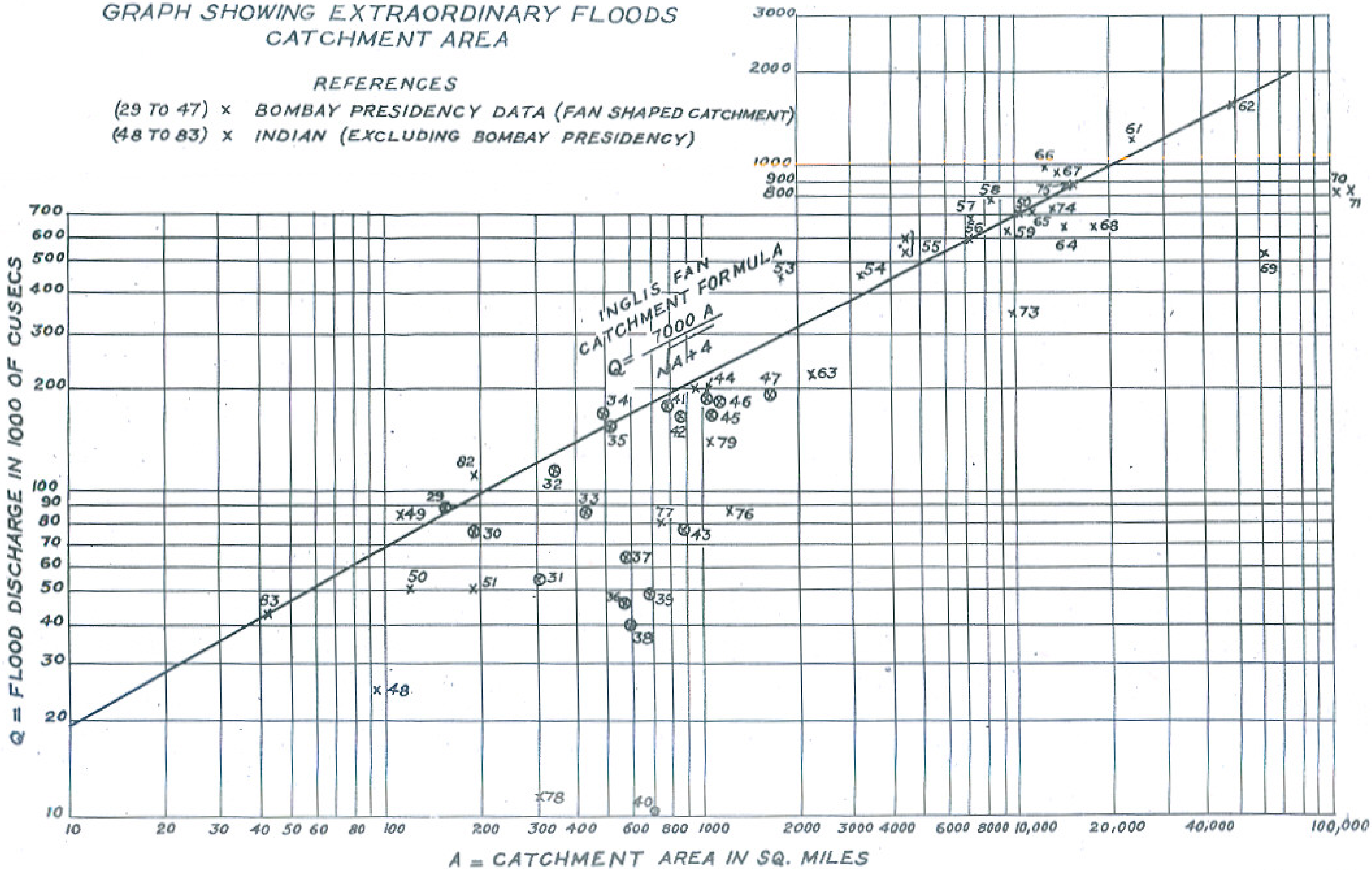


FIG. 16
PAPER NO. 245

GRAPH SHOWING EXTRAORDINARY FLOODS CATCHMENT AREA

REFERENCES

(29 TO 47) x BOMBAY PRESIDENCY DATA (FAN SHAPED CATCHMENT)
(48 TO 83) x INDIAN (EXCLUDING BOMBAY PRESIDENCY)



PUNJAB ENGINEERING CONGRESS
1941.

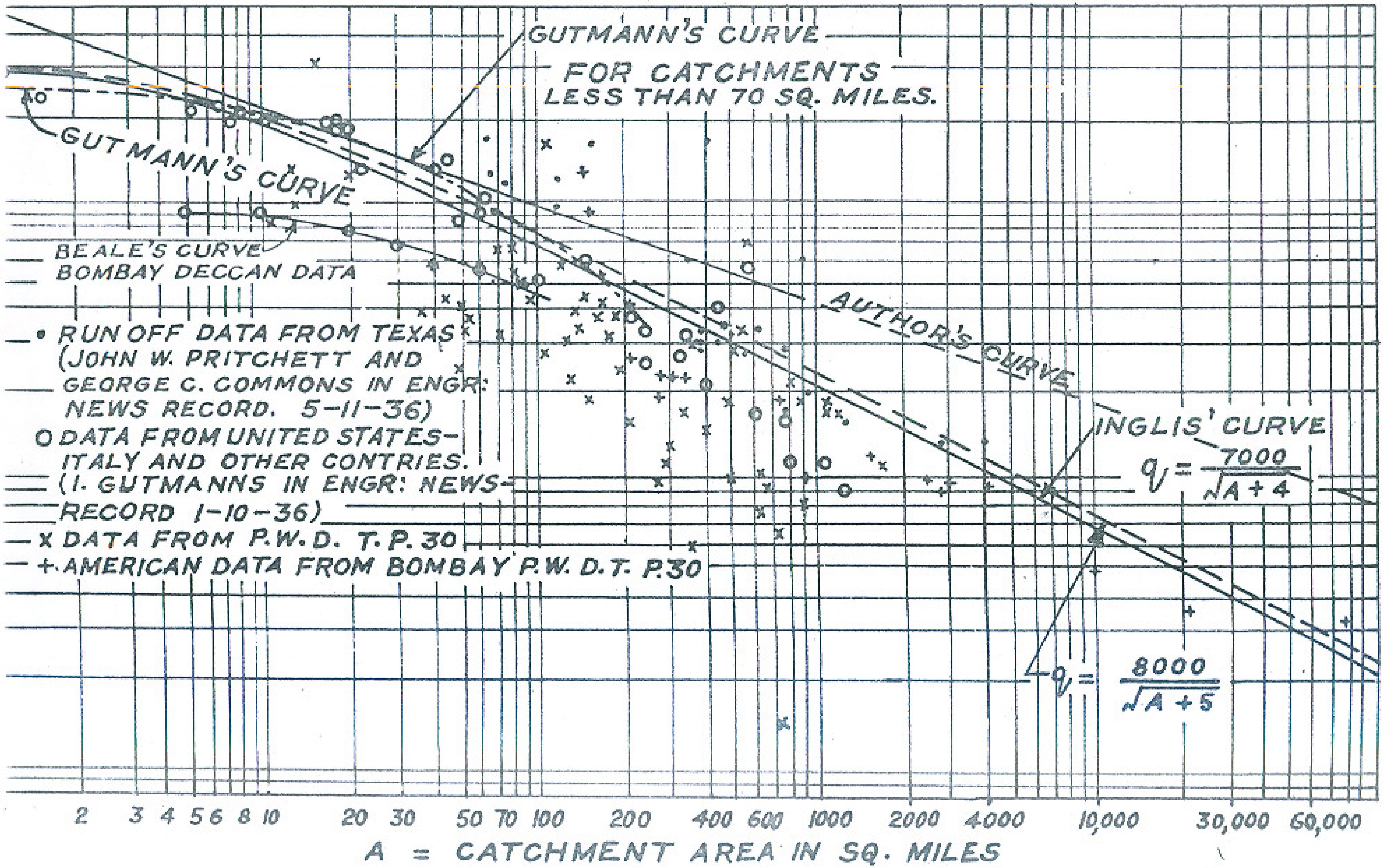
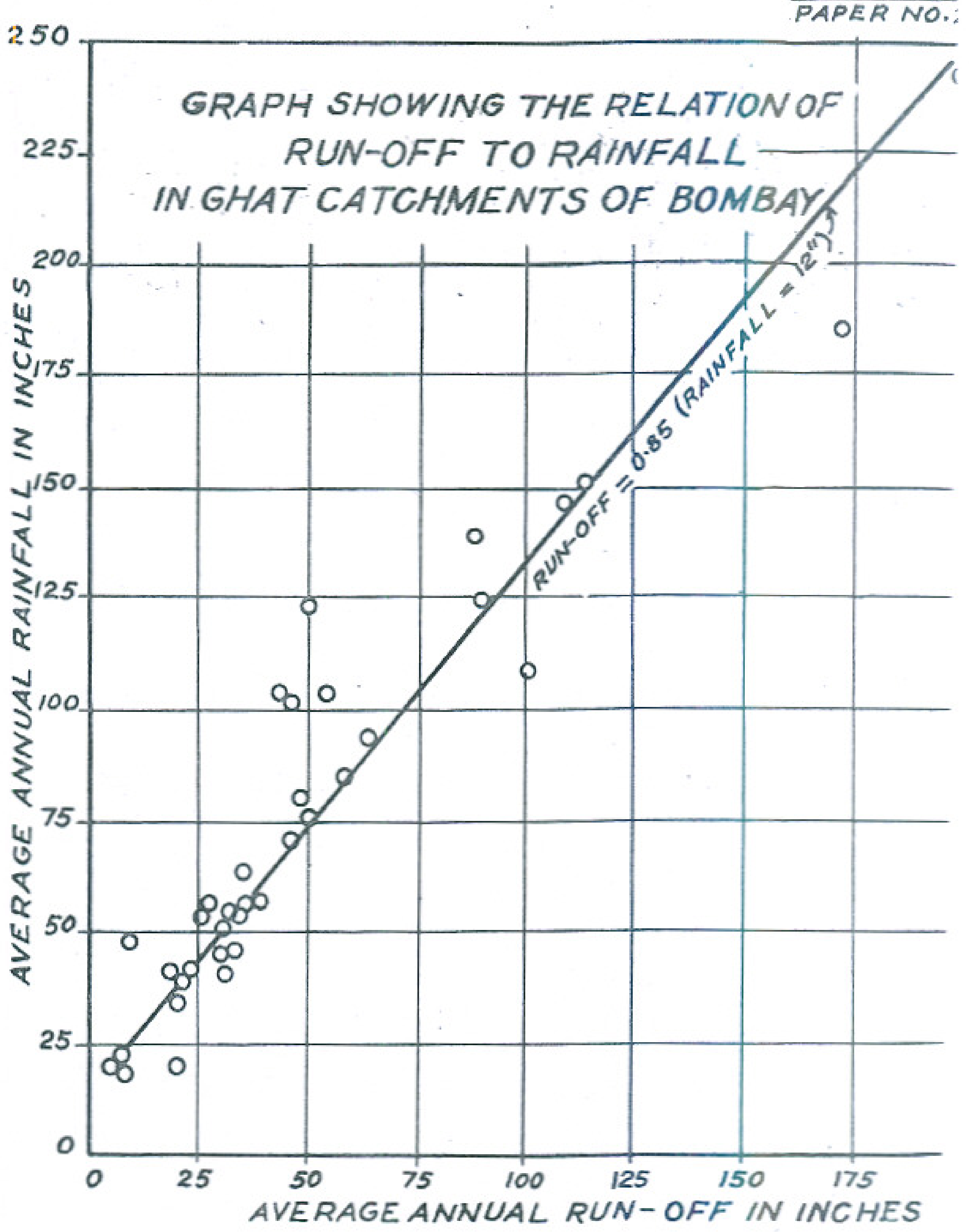

GUTMANN'S CURVE
FOR CATCHMENTS
LESS THAN 70 SQ. MILES.
GUTMANN'S CURVE
BEALE'S CURVE
BOMBAY DECCAN DATA
AUTHOR'S CURVE
• RUN OFF DATA FROM TEXAS (JOHN W. PRITCHETT AND GEORGE C. COMMONS IN ENGR: NEWS RECORD. 5-11-36)
O DATA FROM UNITED STATES-ITALY AND OTHER CONTRIES. (I. GUTMANNS IN ENGR: NEWS-RECORD 1-10-36)
X DATA FROM P.W.D. T.P. 30
+ AMERICAN DATA FROM BOMBAY P.W.D.T. P.30
INGLIS' CURVE
$q = \frac{7000}{\sqrt{A+4}}$
$q = \frac{8000}{\sqrt{A+5}}$
2 3 4 5 6 8 10 20 30 50 70 100 200 400 600 1000 2000 4000 10,000 30,000 60,000
A = CATCHMENT AREA IN SQ. MILES

FIG. 18
PAPER NO.



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1941.