PAPER No. 178.

SILLANWALI DRAIN.

By S. D. Khangar, I.S.E. and N. D. Gulhati, I.S.E.

It is now generally recognised that the most effective method for dealing with our waterlogging troubles is to provide efficient systems of surface drainages in canal irrigated areas.

Under the Five Years Drainage Programme there are many such schemes in various stages of development in the Province at the present time. The Sillanwali Drainage scheme is part of this programme and will serve the area between the Northern and the Southern branches of the Lower Jhelum Canal.

Surface drainage of large irrigated areas is a new problem in Irrigation Engineering, and, as such, there are hardly any set rules or formulae by which one can proceed to design a drainage scheme. The main thing to determine is the probable maximum discharge that is likely to occur at any point on the drain. The rest of the work, that is, the design of the slope and section of the drain and the masonry works does not differ materially from that for other artificial channels.

The formulae for maximum flow off a catchment given in Buckle's and other books on irrigation are generally only applicable to mountainous and sub-mountainous tracts with heavy rainfall. If applied to determine the maximum discharge of drains in the plains, they give very high values.

This will be clearly seen from the table below, where the maximum discharge of the Sillanwali drain with a catchment area of 548 square miles has been worked out.

Name of the formula.	Formula.	Max. discharge of the Sillanwali Drain in cusecs.
Dicken's ..	$825\ M^{\frac{3}{4}}$	93,460
Ryves' ..	$450\ M^{\frac{2}{3}}$	30,130
Dredge's ..	$\frac{1300\ M}{L^{\frac{2}{3}}}$	43,150
Rhind's ..	$\frac{C'' f R M^{p''}}{L}$	1,250
Parker's ..	$640\ F\ I\ M$	8,036

It is thus apparent that it is essential to modify these formulae for flow off a flat highly cultivated catchment area with loamy soil and low rainfall.

An attempt has been made in the following paragraphs to evolve from first principles a method of systematic design of surface drainages, using as an illustration the design of the Sillanwali drain.

The flood discharge off a catchment mainly depends on the following three factors :—

(*i*) the size and configuration of the catchment area.

(*ii*) intensity, duration, and distribution of rainfall. Also the direction of the storm relative to the direction of drainage.

(*iii*) percentage of run off, which again depends on many factors, such as intensity of rainfall, slope of country, nature of soil, intensity of cultivation, temperature and humidity of atmosphere, and condition of the ground whether dry, moist, or wet prior to rainfall. The effect of each of these factors will now be considered.

It is a well-known fact that floods from various portions of a catchment area seldom synchronise. As the area increases the discharge per square mile decreases. The discharge is generally taken to be varying with A^n, where A is the catchment area. The index n has been taken by most writers as equal to $\frac{2}{3}$ or $\frac{3}{4}$. This index, however, depends on the configuration of the country, and, for the Punjab plains, it is usually accepted as 0·5.

It may be taken as axiomatic that other conditions remaining the same, the flood discharge varies directly as the hourly *intensity of rainfall.*

The effect of duration and distribution of rainfall on the discharge is rather complicated. Consider any point P (see Fig. 1) on the drain

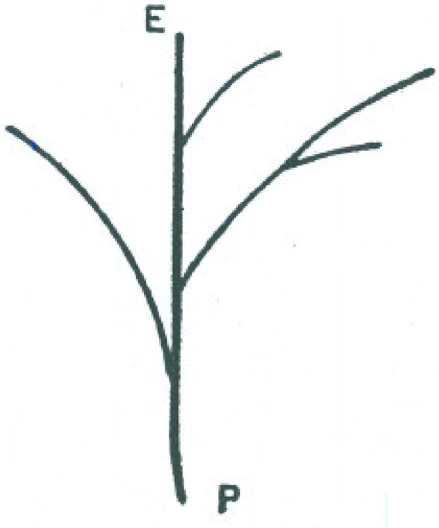


FIG. 1

and let the time taken by rain water to travel from the extreme limits E of the catchment area to this point be called the critical period.

The flood discharge at the point P will be a maximum, when the flood from the extreme limit of the catchment area reaches this point at the same time as the local flood, or in other words it will be maximum, when the rainfall over the whole catchment area of the point lasts for the critical period.

There are usually a number of stations in the catchment area of a drain, where rainfall is being regularly recorded. The relative importance of a rain-gauge station in determining flood discharge will vary as the area represented by that station. For calculating the flood discharge the weighted average rainfall, and not the arithmetical average rainfall over the whole catchment is to be considered.

If $A_1, A_2, A_3, \ldots . A_n$, be the areas controlled by each rain gauge station and $R_1, R_2, R_3 \ldots . R_n$ be the rainfalls at these stations during the critical period, then the weighted average rainfall for the whole area is equal to

$$R = \frac{A_1R_1 + A_2R_2 + A_3 R_3 + \ldots\ldots + A \ R_n}{A_1 + A_2 + A_3 + \ldots\ldots + A_n}$$

As rainfall is measured after every 24 hours, only those points can be selected for calculation of discharge of the drain, whose critical period is 24 hours or a multiple of 24 hours. There is no reliable data available for calculating the weighted average rainfall for other periods.

The hourly intensity of rainfall taken over 24 hours will always be more than that taken for the longer period of 48 hours. Similarly the intensity for 48 hours will be higher than that for 72 hours and so on. In other words, the discharge per square mile of catchment area when measured at a point, whose critical period is 24 hours, will be more than that of a point, whose critical period is more than 24 hours. It is therefore necessary to calculate the intensities of rainfall separately for each of the points, whose critical periods are 24 hours, 48 hours and 72 hours respectively.

Thus on the Sillanwali drain, which is 67 miles long, it will take about three days for water from the upper end of the catchment area to reach the outfall. The discharge at the outfall will be a maximum if, as explained above, the rainfall extends over three consecutive days.

For a point one-third of the way up the drain from the outfall, rainfall need extend for only 48 hours for the flood from the upper end of the catchment area to synchronise with the local flood. Similarly for a point two-thirds of the way up, rainfall need be considered for only 24 hours.

For calculating the intensity of rainfall to give the maximum discharge at the outfall, three consecutive rainy days have to be selected, such that the weighted average rainfall over the catchment during these days is a maximum. This may be termed the maximum general rainfall for three days.

Similarly, for points one-third and two-thirds of the way up the drain from the outfall, two consecutive days, and one day should be considered, and the weighted average for these periods may be termed the maximum general rainfall for two days and maximum general rainfall for one day respectively.

Let T be the critical period in hours of a particular point on the drain, and R the maximum general rainfall for that period, then

$$\frac{R}{T} = I,$$

" I " being termed the critical intensity of rainfall for that point.

With cent per cent run off, one inch of rainfall per hour is equivalent to a run off of 640 cusecs per square mile. Therefore, if P is the percentage of run off, and I the critical intensity, then discharge in cusecs from one square mile of catchment area $= 640 \times I \times P$.

If A be the catchment area, then, as explained previously the discharge varies as $\sqrt{A}$. Therefore the discharge Q for a catchment area of A square miles $= 640 \times I \times P + \sqrt{A}$.

Putting $640 \times I \times P = C$ the formula becomes

$$Q = C\sqrt{A}$$

The portion of the rainfall that finds its way into the drain depends upon the intensity of rainfall, absorption and evaporation losses and the time taken by the water to reach the drain.

Absorption remaining constant, the higher the intensity of rainfall, the greater the percentage of rain water that reaches the drain. The intensity of rainfall is never constant for a considerable period. The smaller the period of observation, the higher can be the rainfall intensity.

During the last 25 years the intensity for various periods has been observed on the Lower Jhelum Canal at different places. The results have been plotted on Plate No. II. A curve has been drawn connecting the highest intensities of rainfall observed for different periods.

Similar curves can be drawn for other catchments. The use of these curves is explained later.

The losses depend on the nature of the soil, temperature and humidity of the atmosphere, and transpiration by plants. Kennedy performed some experiments at Changa Manga to determine this loss. (See Buckley, 1911 Edition, page 241.) About half an acre of forest land was embanked and was subjected to 1·0 ft. depth of flooding. When only two or three inches were left, fresh supplies were admitted. Kennedy found that after saturation for 24 hours, the loss due to absorption and evaporation, etc., was 0·57″ of depth per hour. Assuming that when heavy rain falls the soil will be moderately wet, the above rate of loss of 0·57″ per hour is a fair figure for absorption in the catchment areas of the Punjab plains.

The slope of the country, intensity of cultivation, and the ponding provided by field dowels determine the time taken by rain water to reach the drain. The longer the time taken by rain water in reaching the drain the greater the absorption, and the lesser will be the quantity of water entering the drain. Consider a point P (see Fig. 2) in the catchment area. For rainfall at P to reach the drain, the following conditions must be satisfied :—

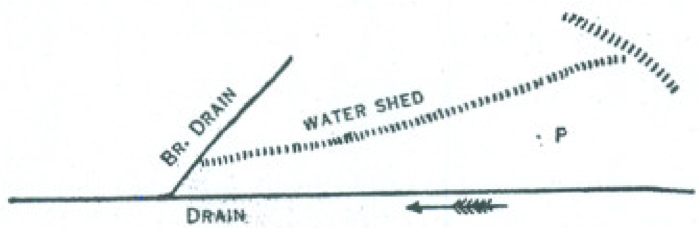


FIG. 2.

(*i*) Intensity of rainfall must be more than 0·57″ per hour. For all intensities less than this, the entire rain water will be absorbed by the soil.

(*ii*) If the time taken by rain water to reach the drain from the point P is T hours, then the total rainfall at P must be more than $\cdot 57 \times T$ inches and must be precipitated in a time equal to or less than T hours.

The discharge reaching the drain from the point P will in most cases be more, if the rainfall is continuous for a period of T hours, than if it fell in a smaller period.

Then the percentage of rainfall that finds its way into the drain will be equal to $\frac{R-D}{R} \times 100$, where R is the intensity of rainfall in inches per hour for the time taken by rain water to reach the drain from a point half way between the drain and the watershed, and D is the sum of the absorption and evaporation in inches per hour.

The time taken by rain water to reach the drain can be fixed by judgment or actual observation and the intensity of rainfall for this time should be obtained from the curve mentioned above.

The absorption and evaporation can be obtained from actual experiments performed in the same manner as Kennedy's experiment.

For the Sillanwali drain with all branch drains excavated, the time taken by rain water to reach the drain from a point half-way between the drain and the watershed, is about 4 hours.

The maximum intensity of rainfall for the period of 4 hours is 0·70" per hour (see Plate No. II). Absorption will be ·57" per hour, so water reaching the drain will be ·70"—·57"=·13" depth of rainfall.

Thus percentage of run off is $=\frac{\cdot 13}{\cdot 70}\times 100 = 18\cdot 6$, say 20%.

For similar catchment areas in the Punjab plains a run off of 20% is a fair figure for the design of drainages.

There are seven rain gauge stations in this area. These stations and the areas under the control of each station, are shown on a plan (Plate No. I). For calculating the discharge at the outfall, all the stations will be taken into account. For working out the discharges at points one-third and two-thirds of the way up the drain from the outfall, only those stations need be considered which are in the catchment area of these points.

A statement is attached (Plate No. III) showing for each of the last 32 years—

- the maximum general rainfall for one day for the head reach ;
- the maximum general rainfall for 2 days for the head and middle reaches combined ;
- the maximum general rainfall for 3 days for the entire catchment area.

A perusal of the statement shows that—

(*i*) the maximum general rainfall for one day is 3·5 inches or of this order and is repeated seven times in 32 years, or roughly once in 4 years. It has been exceeded only once in 1924, when it was 8·5 inches ; 3·5" has been accepted for design.

(*ii*) a maximum general rainfall for 2 days of 5 inches or of this order, is repeated 8 times in 32 years, or once in 4 years. This too has been exceeded only once in 1924, when it was 8·08". Five inches has been accepted for design.

(*iii*) maximum general rainfall for 3 days of 5·5 inches, or that of this order, is repeated 8 times in 32 years or once in 4 years. This has been exceeded only twice in 1914 and 1924 the maximum being 6·48" in 1924. For design, 5·5 has been accepted.

From the above it will be apparent that once in 20 years the capacity of the drain designed on figures accepted above will not be sufficient. It is not considered necessary to provide for the absolute maximum capacity. At the same time, the capacity of drain cannot be reduced as the frequency of rainfall for which it is being designed is high once in 4 years.

The coefficient C_1 for the outfall thus works out to :

$$C_1 = 640 \times I \times P$$

$$= 640 \times \frac{5 \cdot 5}{72} \times \frac{20}{100} = 9 \cdot 8, \text{ say } 10$$

coefficient C_2 for a point one-third of the way up the drain :

$$C_2 = 640 \times \frac{5 \cdot 0}{48} \times \frac{20}{100} = 13 \cdot 3, \text{ say } 13.$$

coefficient C_3 for a point two-thirds of the way up the drain :

$$C_3 = 640 \times \frac{3 \cdot 5}{24} \times \frac{20}{100} = 18 \cdot 7, \text{ say } 19.$$

Coefficients at other points have been interpolated and are shown in column 8 of the capacity statement (Plate No. IV).

These vary from 23 to 10.

To fix the capacity of the drain.—All the subsidiary watersheds and drainages are first marked on a 1" contoured plan, and the catchment areas of these subsidiary drainages are determined by a Planimeter. These are given in column No. 5 of the capacity statement (Plate No. IV).

The method of working out the coefficient of discharge C (column 7) has been given above.

The discharge of various reaches is worked out by formula $Q = C\sqrt{A}$ where A is the catchment area to the end of the reach (column 6).

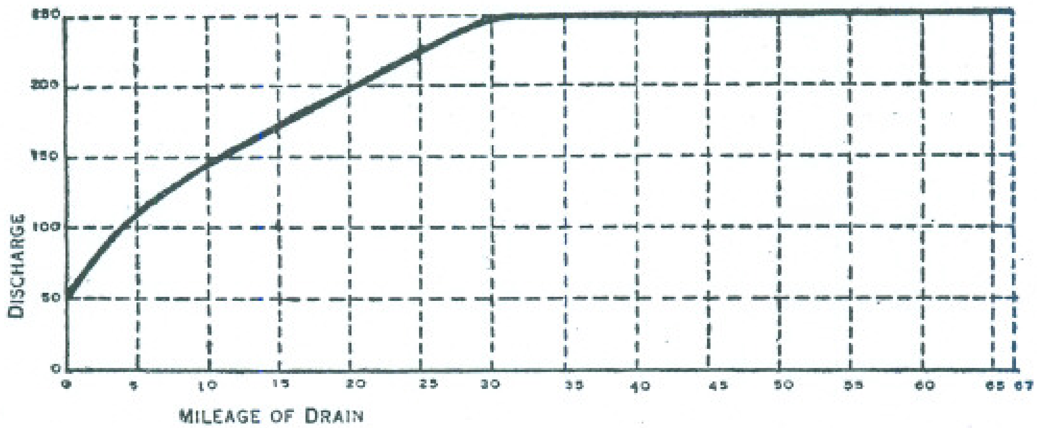
It will be observed that the discharge in some reaches works out to be less than that in the reaches immediately above. This is what should have been expected. It is a well-known fact that the intensity of flood discharge decreases as the flood travels down, provided there is no more inflow. In the upper reaches, the effect of inflow more than counterbalances the decrease in intensity. This is not the case in these particular reaches, as the additional catchment area is small. For these reaches the discharge for purposes of design has been taken to be the same as the maximum worked out for any point above the reach.

The bed width and depth in columns 9, 10, 13 and 14 have been taken from Kennedy's Diagrams assuming $N = 0 \cdot 025$.

It is not, however, necessary to dig to full dimensions in the first instance. The full capacity of the drain is only required when the branch and subsidiary drains are excavated. To start with, it is sufficient to provide for about a third of the ultimate capacity. Columns 13 and 14 show the bed width and depth worked out on this basis. The masonry works, however, must be either built for the ultimate capacity of the drainage, or so designed as to allow for extensions at a later date without excessive cost. In order that the drain may be easily widened at a later date, all spoil from excavation should be thrown on one side only, the side from which the least quantity of water is to get into the drain.

A very interesting feature of the design, and one which is likely to be ignored with serious consequences, if the design is not worked on a rational basis, is the rapidity with which the discharge increases in the head reach. It attains its maximum value about a third of the way down the drain. This is very clearly shown by the curve below.

FIG. 3.



This should be a common feature in every surface drainage and a factor not to be lost sight of.

Sometimes it is seen that, while the general rainfall over a large tract is small, heavy precipitation occurs at a few places. The area under such heavy rainfall is, as a rule, very small. It would be interesting to work out the discharge produced by such a local storm.

Assume that heavy rainfall occurs over an area of one square mile. The time taken by rain water to reach the drain, *i.e.*, the critical period is say, 4 hours. The maximum intensity of rainfall for this time is (See Plate No. II) ·70″ per hour. As the area is small, " I ", as defined previously, is equal to ·70″.

Therefore, Q is equal to $640 \times \frac{20}{100} \times {\cdot}70 \sqrt{A} = 89{\cdot}6 \sqrt{A} = 89{\cdot}6$ say 90 cusecs from an area of one square mile.

If this heavy rainfall was to occur over an area of 5 square miles, (this is very unlikely) the discharge would be equal to $89{\cdot}6\sqrt{5}$ or 200 cusecs. Thus it is seen that the maximum capacity of the drain may be called into play by a heavy local storm over an area of 5 square miles. The effect of such a storm will, however, be short-lived, and the discharge will rapidly fall off as it moves down the drain.

From the above consideration it would appear that the capacity of the Sillanwali drain, as designed, is insufficient in the head reach.

It is quite likely that a discharge of over 100 cusecs may reach the drain at any time in this reach. The drain will overflow and the water will be headed up in the surrounding country. As such a storm is always short-lived (to the extent of a few hours at the most) the headed up water will be drained off in a period of say, 10 or 12 hours and no harm would be caused.

It would be interesting to see, how the coefficient C in the formula $Q=C\sqrt{A}$ as found above for the Sillanwali Drain compares with the coefficients for other drainges. There are a number of sites in the Lower and Upper Jhelum Canal Circles, where flood discharges from known catchments are being recorded every year. These discharges could be used to check the formula derived above, if reliable observations of the hourly intensity of rainfall for the *critical period of the point* were available. Unfortunately most of the catchment areas are small, rain gauge stations are far apart and there is no record kept of the time of precipitation of rainfall during a day. Thus a direct test of the formula is not possible.

The next best thing to do, is to calculate for these drainages the coefficient C in the formula $Q=C\sqrt{A}$ and compare it with values of C found for the Sillanwali Drain. This has been done in the statement below :—

Description of site.	Situation.	Catchment area in Sqr. miles.	Max. Discharge observed. Cusecs.	C.
Inlet	5500 L.J.C. Main Line	0·8	65	72
Kot Baloch inlet ..	16176 Main Line ..	10	634	204
Bagga inlet ..	58438 Main Line ..	27	1047	200
Ala inlet ..	64721 Main Line ..	3	272	157
Badshahpur Syphon ..	107075 Main Line ..	24	128	26
Jaspal Syphon ..	6000 Jaspal Minor ..	5.3	107	46
Mona Syphon ..	163262 Main Line ..	77	500	57
S. B. Syphon ..	40500 Southern Branch	436	589	28
Budhi Nalla Syphon ..	29500 Khadir Branch	460	650	30
Dhiddar Syphon ..	82500 Sulki Branch ..	164	295	23
B. Drain ..	Upper Jhelum Canal	195·7	248	18
Rerka Drain ..	Upper Jhelum Canal	36·6	189	31
B. & Rerka combined	Upper Jhelum Canal	232·3	368	24

The first six have small catchment areas. A storm can cover the whole of the catchment area, the time taken by rain-water to reach the outfall is small, and the intensity of rainfall can be very high for a short period. Therefore, run off from small catchments can be very high.

The results of other sites agree very well with the coefficients worked out for the catchment of the Sillanwali Drain. It should be kept in mind, however, that for the Sillanwali drain the absolute maximum rainfall that occurs once in 20 years has not been taken into consideration. If this were done, the higher coefficient so found would agree more closely with the results of other drainages.

The above method of determining the maximum flood discharge at any point of a catchment, will, it is hoped, be of interest to Railway and Road Engineers, and will be useful to them in determining fairly accurately the water-way required for drainage culverts in highly irrigated areas.

As this problem will be of increasing importance year by year, it is considered desirable that the number of rain-gauge stations should be increased. As a rough rule there should be a rain gauge station every five miles apart, particularly in the head reaches of the drainages.

It is also essential to record the time of duration of each storm along with the rainfall caused by it. It would be useful to instal automatic integrating rain gauges at some of the important stations.

It would be also useful to carry out experiments on the lines of those performed by Kennedy to determine the absorption losses under different conditions.

As new drainages are constructed, and these start functioning, definite orders should be given for frequent observations of discharge at a number of points along each drainage.

The authors realize that the above formula and method for the design of surface drainages are based on a large number of assumptions, but it is hoped, that as our experience in surface drainage increases, all these assumptions will be checked and amended until finally the correct solution is reached. It is with this hope that this paper is being presented to this Congress.

The authors are grateful to Messrs. Natha Singh, Ram Rakha and Minhaj-ud-Din for their many valuable suggestions.

PLATE I

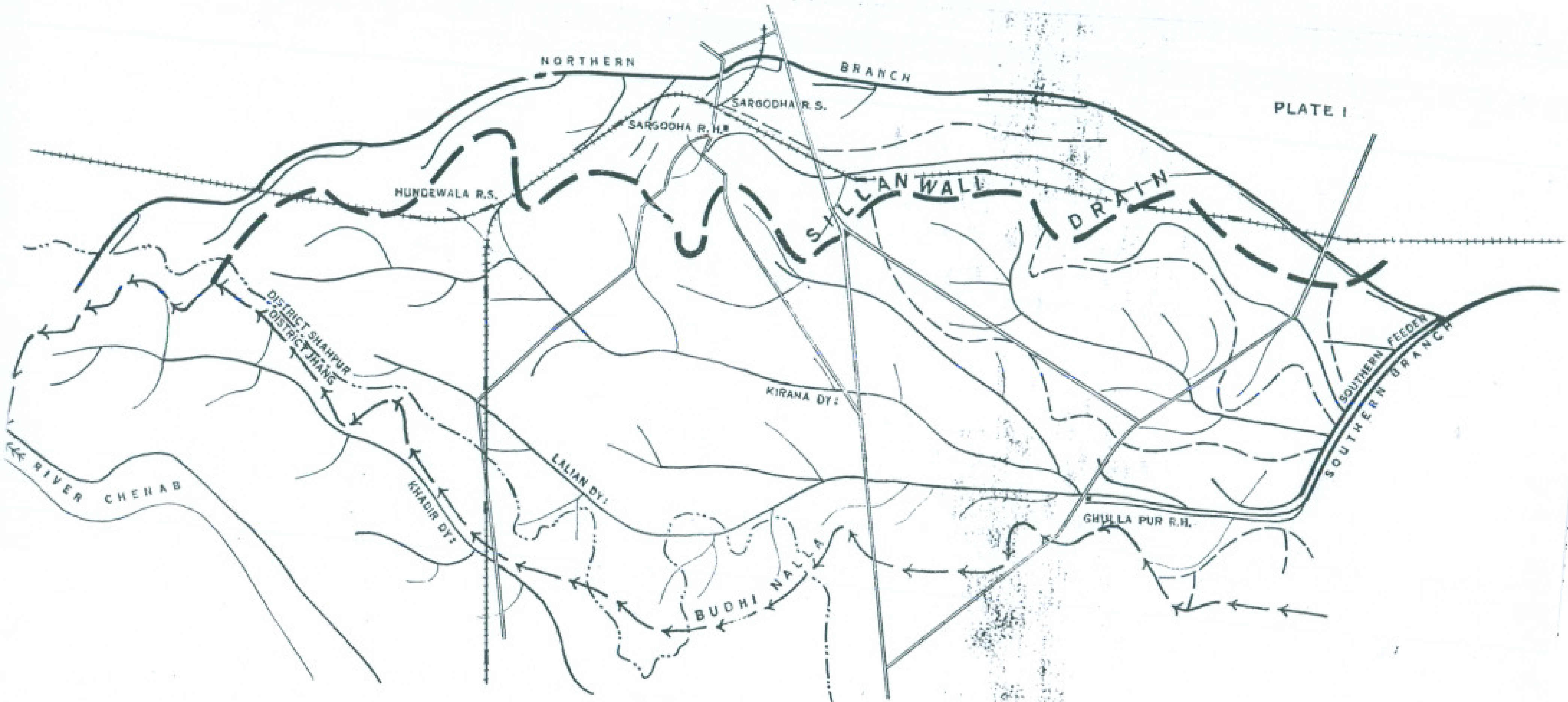
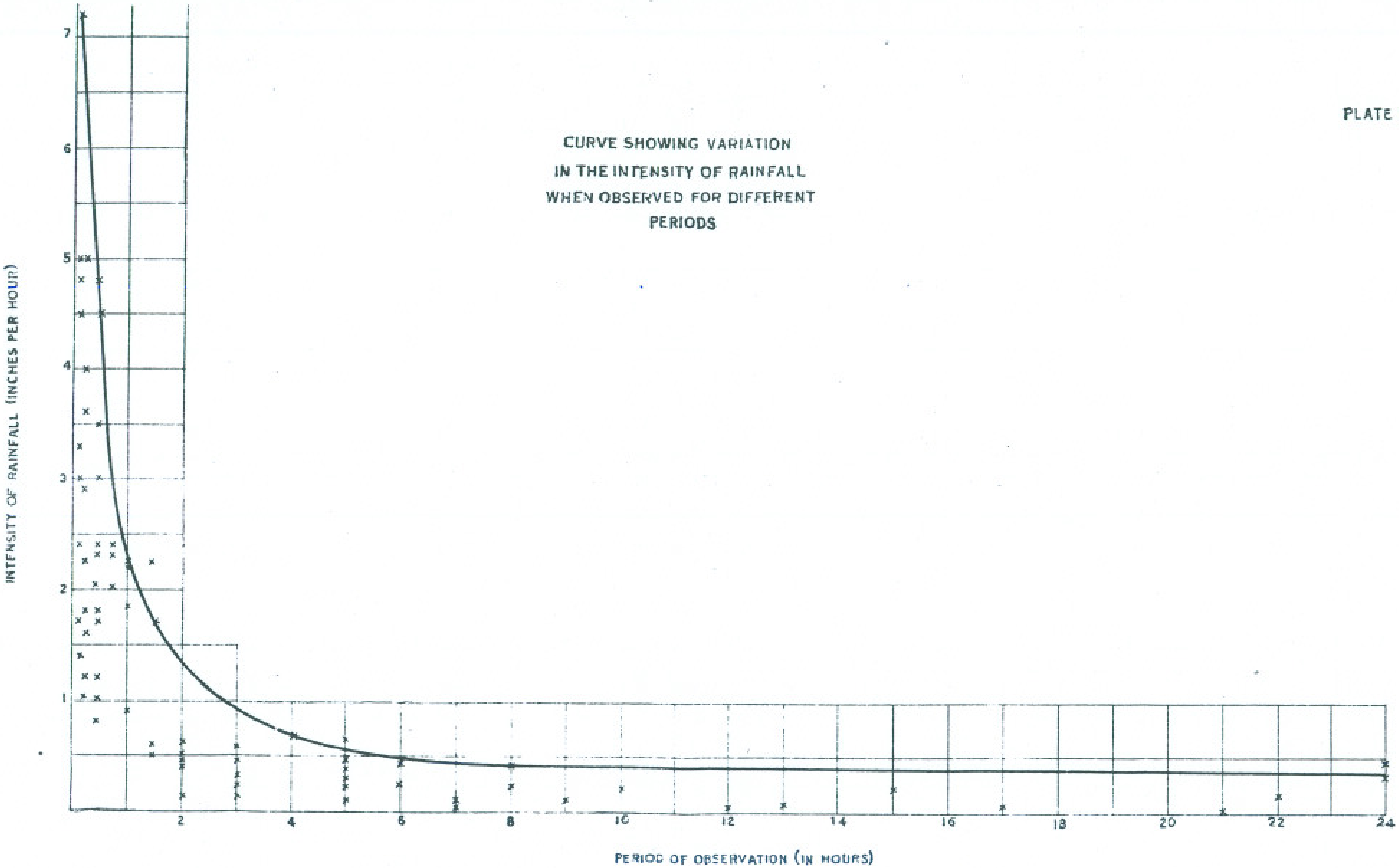

NORTHERN
BRANCH
SARGODHA R.S.
SARGODHA R.H.
HUNDEWALA R.S.
SILLANWALI DRAIN
DISTRICT SHAHPUR
DISTRICT JHANG
KIRANA DY.
LALIAN DY.
KHADIR DY.
RIVER CHENAB
BUDHI NALLA
GHULLA PUR R.H.
SOUTHERN FEEDER
SOUTHERN BRANCH

PLATE II


CURVE SHOWING VARIATION
IN THE INTENSITY OF RAINFALL
WHEN OBSERVED FOR DIFFERENT
PERIODS
INTENSITY OF RAINFALL (INCHES PER HOUR)
1
2
3
4
5
6
7
PERIOD OF OBSERVATION (IN HOURS)
2
4
6
8
10
12
14
16
18
20
22
24

Name of Rain-gauge Station.	Catchment areas controlled by stations. Sq. Miles.	Index figure for calculating weighted average.	1902.		1903.		1904.		1905.		1906.		1907.		1908.		1909.		
			Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Act. rain-fall.
Fakirian	60	.6	0.80	0.48	1.50	0.90	0.15	0.09	5.60	3.36	4.9	2.94	2.60	1.56	..	..	0.60	0.36	1.
Wan	30	.3	0.90	0.27	0.60	0.18	3.15	0.95	5.00	1.50	3.2	0.96	2.20	0.66	3.05	0.92	1.20	0.30	4.
Ghullapur	90	.9	..	..	2.70	2.43	2.40	2.16	5.40	4.86	3.0	2.70	1.00	0.90	6.00	5.40	2.20	1.98	4.
Beriwala	130	1.3	4.40	5.72	0.20	0.26	..	..	0.35	0.46	.	..	0.05	0.07	0.70	0.41	0.10	0.13	3.
Total ..	..	3.1	..	6.47	..	3.77	..	3.20	..	10.18	..	6.60	..	3.19	..	7.23	..	2.83	..
Weighted average	..	—	..	2.09	..	1.22	..	1.03	..	**3.29**	..	2.13	..	1.03	..	2.33	..	0.91	..
Fakirian	60	.6	0.60	0.48	2.3	1.38	0.15	.09	5.62	3.37	4.9	2.94	1.85	1.11	2.70	1.62	0.60	0.36	3.
Wan	30	.3	0.90	0.27	3.3	.99	3.15	.95	5.15	1.55	3.2	0.96	1.70	0.51	3.08	0.92	8.30	0.99	6.
Ghullapur	90	.9	..	..	2.2	1.98	2.40	2.16	5.60	5.04	3.0	2.70	1.50	1.35	7.75	6.98	2.20	1.98	5.
Beriwala	130	1.3	4.4	5.72	..	..	.56	0.73	3.90	5.07	1.5	1.95	0.08	0.10	1.30	1.69	.00	1.30	4.
Sargodha	110	1.1	..	..	..	..	1.47	1.62	3.40	3.74	1.7	1.87	1.20	1.32	4.30	4.73	.45	1.60	0.
Total	..	4.2	..	6.47	..	4.35	..	5.55	..	18.77	..	10.42	..	4.39	..	15.94	..	6.23	..
Weighted average	..	—	..	1.54	..	1.04	..	1.32	..	**4.47**	..	2.48	..	1.05	..	**3.80**	..	1.48	..
Fakirian	60	.6	.8	0.48	2.5	1.50	.15	.09	5.63	3.38	5.6	3.36	1.85	1.11	3.10	1.86	.60	0.36	4.4
Wan	30	.3	.9	0.27	3.5	1.05	3.15	.95	5.85	1.76	3.2	0.96	1.70	0.51	3.85	1.16	.30	0.99	6.
Gullapur	90	.9	..	..	2.6	2.34	2.40	2.16	6.30	5.67	3.3	2.97	1.50	1.35	8.05	7.25	.20	2.88	5.
Beriwala	130	1.3	4.4	5.72	..	..	.56	0.73	3.90	5.07	1.5	1.95	0.08	0.10	1.40	1.82	.00	1.30	4.7
Sargodha	110	1.1	..	..	..	..	1.47	1.62	4.10	4.51	1.7	1.87	1.20	1.32	4.40	4.84	.95	2.15	4.7
Rodian	100	1.0	..	..	..	..	**1.4**	1.40	**4.10**	4.10	**1.7**	1.70	**1.2**	1.20	**4.4**	4.40	**1.95**	1.95	**4.7**
Ramdana	30	.3	**0.2**	0.06	..	..	..	..	4.20	1.26	.7	0.21	1.60	0.48	6.10	1.83	.90	0.57	1.
Total ..	..	5.5	..	6.53	..	4.89	..	6.95	..	25.75	..	13.02	..	6.07	..	23.16	..	10.20	..
Weighted average	..	—	..	1.19	..	0.89	..	1.26	..	**4.69**	..	2.37	..	1.10	..	**4.21**	..	1.86	..

RAINFALL STATEMENT

THE SILLANWALI DRAIN CATCHMENT AREA.

1907.		1908.		1909.		1910.		1911.		1912.		1913.		1914.		1915.		1916.		1917.		1918.		1919.		1920.		1921.		
Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actua rain-fall.
MAXIMUM GENERAL RAINFALL FOR ONE DAY.																														
2.60	1.56	..	..	0.60	0.36	1.60	0.96	..	..	4.120	2.52	2.20	1.32	4.20	2.52	1.20	0.72	2.90	1.74	3.40	2.04	0.50	0.30	3.6	2.16	1.20	0.72	2.16	1.30	2.80
2.20	0.66	3.05	0.92	1.20	0.36	4.50	1.35	2.25	0.68	5.40	1.62	1.10	0.33	1.80	0.54	1.40	0.42	1.20	0.36	0.26	0.08	1.10	0.33	0.63	0.19	..	..	1.30	.39	5.00
1.00	0.90	6.00	5.40	2.20	1.98	4.45	4.01	0.70	0.63	1.20	1.08	1.35	1.22	2.00	1.80	0.50	0.45	1.40	1.26	0.25	0.23	1.10	0.99	0.23	0.21	..	..	0.70	.63	1.60
0.05	0.07	0.70	0.41	0.10	0.13	3.30	4.29	0.05	0.07	0.05	0.07	1.15	1.50	0.90	1.17	0.05	0.07	1.17	1.52	5.00	6.50	0.60	0.78	0.75	0.98	.52	.68	5.80	7.54	1.10
..	3.19	..	7.23	..	2.83	..	10.61	..	1.38	..	5.29	..	4.37	..	6.03	..	1.66	..	4.88	..	8.85	..	2.40	..	3.54	..	1.40	..	9.86	..
..	1.03	..	2.33	..	0.91	..	3.42	..	0.45	..	1.71	..	1.41	..	1.95	..	0.54	..	1.57	..	**2.86**	..	0.77	..	1.14	..	0.45	..	**3.18**	..
MAXIMUM GENERAL RAINFALL FOR TWO DAYS.																														
1.85	1.11	2.70	1.62	0.60	0.36	3.30	1.98	..	..	7.70	4.62	4.20	2.52	5.50	3.30	1.20	0.72	2.50	1.74	5.40	3.24	0.50	0.30	2.9	1.74	1.85	1.10	2.96	1.78	3.50
1.70	0.51	3.08	0.92	8.30	0.99	6.50	1.95	2.25	0.68	6.40	1.92	2.30	0.69	5.30	1.59	1.40	0.42	1.20	0.36	0.91	0.27	1.10	0.33	4.6	1.38	0.20	0:06	1.50	0.45	7.93
1.50	1.35	7.75	6.98	2.20	1.98	5.25	4.73	0.70	0.63	2.40	2.16	1.95	1.76	3.80	3.42	0.5	0.45	1.40	1.26	0.25	0.23	1.10	0.99	1.7	1.53	..	..	1.47	1.32	2.58
0.08	0.10	1.30	1.69	.00	1.30	4.70	6.11	0.05	0.07	0.05	0.07	1.95	2.28	4.25	[illegible]	0.05	0.07	1.17	1.52	5.00	6.50	0.60	0.78	0.50	0.65	0.52	0.68	8.00	10.40	1.45
1.20	1.32	4.30	4.73	.45	1.60	0.30	0.33	..	..	0.70	0.77	0.00	.66	6.30	6.95	..	..	1.40	1.54	0.85	0.94	1.14	1.25	1.9	2.09	.15	0.17	4.75	5.23	0.35
..	4.39	..	15.94	..	6.23	..	15.10	..	1.38	..	9.54	..	7.91	..	20.77	..	1.66	..	6.42	..	11.18	..	3.65	..	7.39	..	2.02	..	19.18	..
..	1.05	..	**3.80**	..	1.48	..	**3.60**	..	0.33	..	2.27	..	1.88	..	**4.95**	..	0.49	..	1.53	..	2.65	..	0.87	..	1.76	..	0.48	..	**4.57**	..
MAXIMUM GENERAL RAINFALL FOR THREE DAYS.																														
1.85	1.11	3.10	1.86	.60	0.36	4.40	2.64	0.50	0.30	9.00	5.40	5.20	3.12	7.50	4.50	0.30	0.18	5.54	3.32	5.40	3.24	0.50	0.30	3.86	2.32	1.85	1.11	6.23	3.74	3.70
1.70	0.51	3.83	1.16	.30	0.99	6.50	1.95	2.35	0.71	6.77	2.03	4.60	1.38	5.30	1.59	.70	0.21	2.70	0.81	0.91	0.27	1.10	0.33	4.60	1.38	0.90	0.27	2.65	0.80	8.83
1.50	1.35	8.05	7.25	.20	2.88	5.25	4.73	0.70	0.63	2.40	2.16	2.85	2.30	3.80	3.42	2.00	1.80	1.70	1.53	0.25	0.23	1.10	0.99	1.70	1.53	0.73	0.66	1.92	1.73	2.58
0.08	0.10	1.40	1.82	.00	1.30	4.70	6.11	0.10	0.13	0.05	0.07	2.65	3.45	7.25	9.43	1.45	1.89	0.70	0.91	5.00	6.50	0.60	0.78	0.50	0.65	0.52	0.68	9.10	11.83	1.45
1.20	1.32	4.40	4.84	.95	2.15	4.70	5.17	..	..	0.70	0.77	2.50	2.75	7.70	8.47	..	..	0.65	0.72	0.85	0.94	1.14	1.25	1.90	2.09	0.15	0.17	5.45	6.00	0.35
1.2	1.20	**4.4**	4.40	**1.95**	1.95	**4.7**	4.70	..	..	**0.70**	0.70	**2.50**	2.50	5.36	5.35	..	..	0.20	0.20	0.53	0.53	..	..	4.90	4.90	..	..	4.08	4.08	0.30
1.60	0.48	6.10	1.83	.90	0.57	1.50	0.45	..	..	..	..	1.90	0.57	6.80	2.04	0.90	0.27	..	..	1.87	0.56	0.5	0.15	3.00	0.90	0.30	0.09	3.65	1.10	0.30
..	6.07	..	23.16	..	10.20	..	25.75	..	1.77	..	11.13	..	16.07	..	34.80	..	4.35	..	7.49	..	12.27	..	3.80	..	13.77	..	2.98	..	29.28	..
..	1.10	..	**4.21**	..	1.86	..	**4.69**	..	0.32	..	2.02	..	2.92	..	**6.33**	..	.79	..	1.36	..	2.23	..	0.69	..	2.60	..	0.54	..	**5.32**	..

PLATE No. III.

1921.		1922.		1923.		1924.		192[illegible].		1926.		1927.		1928.		1929.		1930.		1931.		1932.		1933.		Remarks.
[illegible]ual [illegible]n- [illegible]ll.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduce rain-fall.	Actual rain-fall.	[illegible]duced [illegible]ain-[illegible]all.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	Actual rain-fall.	Reduced rain-fall.	
16	1.30	2.80	1.68	0.20	0.12	10.96	6.58	2.05	1.23	4.30	2.58	..	..	3.30	1.98	2.95	1.77	2.2	1.32	0.31	0.19	1.70	1.02	3.60	2.16	
30	.39	5.00	1.50	..	..	4.00	1.20	1.50	.45	4.23	4.23	0.50	.15	4.20	1.26	2.20	.66	1.15	0.35	1.73	0.52	1.70	0.51	2.50	0.75	
70	.63	1.60	1.44	..	..	9.77	8.79	1.37	.23	3.05	2.75	2.65	2.39	1.30	1.17	0.95	.87	0.42	0.38	1.38	1.24	1.55	1.40	2.8	2.52	Average (weighted) intensity in 24 years accepted as 3.5 inches.
80	7.54	1.10	1.43	3.90	5.07	3.60	4.68	1.23	1.63	2.40	3.12	3.00	3.90	3.40	4.42	3.60	4.68	0.33	0.43	1.50	1.95	3.6	4.68	1.25	1.63	
	9.86	..	6.05	..	5.19	..	21.25	..	1.54	..	9.72	..	6.44	..	8.83	..	7.97	..	2.48	..	3.90	..	7.61	..	7.06	
	3.18	..	1.95	..	1.67	..	**6.85**	..	1.46	..	**3.14**	..	2.08	..	**2.85**	..	2.57	..	0.80	..	1.26	..	2.46	..	3.23	
96	1.78	3.50	2.10	0.20	0.20	12.75	7.65	3.65	.19	4.41	2.65	2.50	1.50	3.30	1.98	4.02	2.41	4.2	2.52	1.76	1.06	2.22	1.33	4.50	2.70	
50	0.45	7.93	2.38	0.26	0.08	6.20	1.86	2.00	.60	4.44	1.33	1.65	0.50	4.20	1.26	2.50	0.75	1.40	0.42	1.75	0.53	1.85	0.56	3.35	1.01	
47	1.32	2.58	2.32	0.69	0.62	12.99	11.69	1.12	.01	3.95	3.56	2.17	1.95	1.30	1.17	0.95	0.86	0.87	0.78	.94	0.85	1.65	1.49	3.60	3.24	
[illegible]	10.40	1.45	1.89	3.90	5.07	5.04	6.55	2.00	.60	3.40	4.42	1.20	1.56	3.45	4.49	3.60	4.68	0.33	0.43	..	..	4.67	6.07	5.45	7.09	Average (weighted) intensity in 48 hours accepted as 5 inches.
75	5.23	0.35	0.39	2.20	2.42	5.60	6.16	1.20	.32	3.40	3.74	1.20	1.32	2.35	2.59	2.67	2.94	0.57	0.63	1.70	1.87	3.33	3.66	3.90	4.29	
	19.18	..	9.08	..	8.31	..	33.92	..	7.72	..	15.70	..	6.83	..	11.49	..	11.64	..	4.78	..	4.31	..	13.11	..	18.33	
	4.57	..	2.16	..	1.98	..	**8.08**	..	1.84	..	**3.74**	..	1.63	..	2.74	..	2.79	..	1.14	..	1.03	..	3.12	..	**4.36**	
23	3.74	3.70	2.22	0.20	0.12	12.85	7.71	2.27	.36	4.41	2.65	2.50	1.50	3.30	1.98	4.02	2.41	4.2	2.52	1.76	1.06	2.22	1.32	3.08	1.85	
65	0.80	8.83	2.65	0.26	0.08	6.90	2.07	1.60	.48	4.44	1.33	1.65	0.50	4.20	1.26	2.50	0.75	1.40	0.42	1.75	0.53	1.85	0.56	4.65	1.30	
92	1.73	2.58	2.32	0.69	0.62	13.29	11.96	1.82	.64	3.95	3.56	2.17	1.95	1.30	1.17	0.99	0.89	0.87	0.78	.94	0.85	1.65	1.49	3.85	3.47	
10	11.83	1.45	1.89	4.30	5.59	5.04	6.55	1.85	.41	3.53	4.59	1.20	1.56	3.45	4.49	3.72	4.84	0.37	0.42	..	..	4.67	6.07	4.30	5.59	
45	6.00	0.35	0.39	3.4	3.74	5.60	6.16	3.10	.41	3.40	3.74	1.20	1.32	2.35	2.59	2.69	2.96	0.57	0.63	1.72	1.89	3.33	3.66	6.93	7.62	Average (weighted) intensity in 72 hours accepted as 5.5 inches.
08	4.08	0.30	0.30	6.1	6.10	0.45	0.45	3.70	.70	6.50	6.50	0.55	0.55	0.72	0.72	0.37	0.37	0.11	0.19	.55	.55	.90	.90	4.55	4.55	
55	1.10	0.30	0.09	2.45	0.74	2.50	0.75	5.25	.58	6.30	1.89	1.00	0.30	0.66	0.20	1.47	0.44	0.64	0.19	1.25	.38	..	..	9.15	2.75	
	29.28	..	9.86	..	16.99	..	35.65	..	[illegible]	..	24.26	..	7.68	..	12.41	..	12.66	..	5.15	..	5.26	..	14.00	..	27.13	
	5.32	..	1.79	..	3.09	..	**6.48**	..	.65	..	**4.42**	..	1.40	..	2.26	..	2.30	..	0.94	..	0.96	..	2.55	..	**4.94**	

SILLANWALI DRAIN.

CAPACITY STATEMENT.

R. D. of Intake.	Name of Intake.	Reach. From	Reach. To	Catchment area tapped by intake.	Total catchment area to end of reach = A.	Coefficient C in formula $Q = C\sqrt{A}$.	Ultimate Design. Discharge Q	Ultimate Design. Bed width. B	Ultimate Design. Depth. D	Ultimate Design. Slope. S	Present Design. Discharge Q	Present Design. Bed width B	Present Design. Depth D	Present Design. Slope S
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		3,35,000	3,27,000											
3,35,000	Direct R & L ..			5.0	5.0	23	51	11	2.2	1/2000	17	5.0	1.9	1/2000
		3,27,000	3,12,000											
3,27,000	Direct L & R ..			4.4	9.4	23	70	14	2.4	1/2000	23	7.0	1.9	1/2000
		3,12,000	2,96,000											
3,15,000	1 L Branch Drain ..			8.3										
3,15,000	Direct right			3.0										
3 [illegible]	Direct left			5.3	26.0	22	112	19	2.6	1/2000	37	10	2.0	1/2000
				16.6										
		2,96,000	2,60,000											
2,96,000	Direct right			10.5										
2,96,000	Direct left			7.9	44.4	21	140	23	3.2	1/4000	47	11	2.3	1/4000
				18.4										
		2,60,000	2,38,000											
2,60,000	Direct right			5.3										
2,60,000	Direct left			6.0	55.7	19	142	25	3.2	1/5000	47	15	2.3	1/5000
				11.3										
		2,38,000	1,92,000											
2,38,000	2 L Branch Drain ..			63.0										
2,10,000	1 R Drain			10.0										
	Direct right			5.0										
	Direct left			5.1	138.8	17	200	30	3.6	1/5000	67	18	2.6	1/5000
				83.1										
		1,92,000	1,66,000											
1,92,000	3 L Branch Drain ..			105.3										
1,92,000	Direct right			6.0										
1,72,000	4 L Branch Drain ..			8.8	258.9	15.5	239	34	3.8	1/5000	83	19	2.8	1/500
				120.1										
		1,66,000	1,37,000											
1,66,000	Direct right			10.3										
1,66,000	Direct left			0.6										
1,49,000	5 L Branch Drain ..			5.0	274.8	14	232	36	4.0	1/6666	83	20	3.0	1/6666
				15.9										
		1,37,000	1,21,000											
1,37,000	6 L Branch Drain ..			76.8	351.6	13	244	36	4.0	1/6666	83	20	3.0	1/6666
		1,21,000	98,000											
1,21,000	2 R Branch Drain ..			73.0										
1,21,000	Direct left			1.2										
1,16,000	3 R Branch Drain & Direct right ..			10.6	436.4	12	250	36	4.0	1/6666	81	20	3.0	1/6666
				84.8										
		98,000	50,000											
98,000	7 L Branch Drain & Direct left. ..			32.7										
98,000	Direct right ..			15.2										
66,000	8 L Branch Drain & Direct left. ..			7.3										
66,000	4 R Branch Drain & Direct right. ..			11.4	503.0	11	216	36	4.0	1/6666	83	20	3.0	1/6666
				66.6										
		50,000	0											
50,000	9 L Branch Drain ..			11.6										
50,000	Direct left			3.3										
50,000	Direct right			18.2										
17,000	10 L Branch Drain ..			11.7	547.8	10	231	36	4.0	1/6666	83	20	3.0	1/6666
				44.8										

Note.—1. The inflow into the main drain in any particular reach from its catchment area (direct) has been considered as if it entered the drain at the head of the reach.

2. The value of Kutter's "N" has been assumed as 0.0250.

DISCUSSION.

In introducing his paper, **Mr. Khangar** said the authors last summer had to prepare a scheme for the construction of the Sillanwali Drain of the Lower Jhelum Canal. What should be the capacity of the drain in its various reaches? That question did not offer an easy solution. Various formulae were tried. The results were given in the paper. As would be seen, that whereas the lowest was of the order of one thousand cusecs, the highest was as much as one hundred thousand. Even the lowest appeared to be much too high. It led the authors to study the question from first principles.

The size of the catchment area was naturally the first factor to be considered. Rainfall on different parts of the catchment area seldom synchronises. The index depended on the degree on the synchronisation of rainfall. It would be 1·0 for 100 p.c. synchronisation and less if the synchronisation was not complete.

The configuration of the catchment area, and the existence or absence of ponds or reservoirs fixed the time taken by rain water in travelling from the catchment to the nearest point on the drain. That time affected the percentage of run off.

On the kind and condition of soil would depend the amount of rainfall absorbed by the soil.

Next came rainfall. The heavier the rainfall, the larger the flood discharge. But that was not the entire truth. There were various other factors that played important parts. The rate at which rain falls, the time during which it fell and the way it was distributed over the catchment area all had their effects, which had been fully discussed in the paper.

In determining the critical period, due consideration must be given to the delaying effect of any natural pond or reservoir in the alignment of the drainage.

Using the method described in the paper, the authors had calculated the discharge of the Budhinallah Drain at its crossing with the Lyallpur-Sargodha Railway line for the rainfall that occurred from 20th to 25th August, 1933 and had found it to be 267 cusecs against 300 actual.

It had been stated in the paper that the intensity of flood discharge decreased as the flood travelled down. An experiment was performed to determine the magnitude of the decrease in intensity. Two days after a distributary had been closed, a constant discharge was passed into it for about 3 hours after which the supply was suddenly cut off. All the outlets etc. had been closed beforehand. On two falls, 8 miles and 12 miles away from the head, observations were made of the water that passed over the crests. The results were shown in Plate V.

It would be seen that the intensity of the discharge 8 miles from the head was reduced to two-thirds and at 12 miles to one-half of what it was at the head. In a drain, as water was bound to overflow at many places, the decrease in intensity of discharge would be still more pronounced.

Since writing the paper, the authors had carried out an experiment to determine the absorption loss. The method adopted was similar to that of Kennedy as described in the paper. The experiment was conducted immediately after a rainfall of 1·5". The results are shown in Plate VI. It will be seen that during the first day the absorption amounted to ·55 inches per hour. On the second day it was 49 and on the third day it was ·47. The results closely agreed with those obtained by Kennedy.

The paper deals with the surface drainage of irrigated areas, but the method evolved is of general application, and can be used in determining the flood discharge of any catchment area. The area of the catchment is known. Rainfall records are generally available for a fairly long period. The critical period can be estimated fairly accurately. The maximum intensity curves as shown on Plate II would probably not show a variation from place to place. That could however be easily checked. Absorption losses are also easily determinable and all that is required is to use the data in the way described in the paper.

The analytical study of the surface drainage problem had brought into prominence a very important result that is deserving of consideration. It has been stated that little water is going to find its way in to the drain unless the intensity of rainfall is more than ·57" per hour and a rainfall of that or higher intensity must continue for a number of hours before any water from the distant parts of the catchment area finds its way into the drain. For how many days in the year does such a rainfall occur in the Punjab plains? The records show that on the average, such a rainfall occurs about two or three times in a year.

It has been shown in the paper that not more than 20 per cent of such high rainfall is likely to get into the drain. For the lighter showers the percentage of run-off will be considerably less. The authors estimate that with the main and branch drains in operation, they should not expect the drainage system to drain off more than 10 per cent of the total monsoon rainfall. The remaining 90 per cent of the rainfall must go to the subsoil.

The author remarked that Dr. McKenzie Taylor had worked out that for the area of the Upper Chenab Canal the water table would not rise between June and October if the total monsoon rainfall did not exceed 2·5". Working on similar lines and using the data of Dr. McKenzie Taylor the authors had drawn a graph (Plate VII) connecting the monsoon rainfall and the net yearly rise or fall (June to June) in the water-table produced by it. That graph gave the regression formula $\delta d = \cdot 17\,R - 1\cdot 87$ and showed that if the monsoon rainfall was 11 inches the water table would remain stationary.

The average monsoon rainfall in that area was 15 inches. Thus the water table could only remain stationary if 4 inches or say 27 per cent of the total monsoon rainfall could be drained off, but it had been shown that it will not be possible to drain off more that 10 per cent. Therefore it is not reasonable to expect that the construction of the main drains alone will remove all waterlogging troubles. The water table will continue to rise, only the rate of rise will decrease.

To ensure that the subsoil water table does not rise further or that it will fall, it is necessary to increase the percentage of run off. This can be done by reducing the time taken by the rain water to reach the drain, and to achieve that object the construction of branch and subsidiary drains is most essential.

The authors emphasized that it was not only necessary to remove rain water, but to remove it in the quickest possible time, as absorption losses were relatively high. Therefore, all drains whether main, branch or subsidiary should be constructed for sufficient capacity.

CALCULATIONS FOR DISCHARGE OF BUDHINALLAH DRAIN AT ITS CROSSING WITH SARGODHA-LYALLPUR LINE.

Rainfall in Inches.

August 1933.	Wasu.	Phalia.	Bachar.	Busal.	Fakirian.	Wan.	Ghulla-pur.	Kot Naja.	Kandi-wala.
20th ..	3·90	3·10	2·30	1·89	3·60	2·5	2·8	2·50	1·30
21st ..	2·44	2·70	2·90	4·25	0·9	0·85	0·8	2·07	2·60
22nd ..	0·30	0·32	0·60	1·00	1·53	2·5	1·30	1·00	0·77
23rd ..	1·06	0·65	0·90	0·62	0·65	1·30	1·75	2·40	4·00

Length of drain=67 miles.

Critical period=3 days.

Name of rain-gauge station.	Area represented by rain gauge station.	Rainfall on 20, 21 & 22 August 1933.	Product.
Wasu	55	6.64	354
Phalia	80	6.12	500
Bachar	55	6.70	391
Busal	130	7.14	928
Fakirian	30	6.03	181
Wan	70	5.85	410
Ghullapur	55	4.90	270
Kot Naja	55	5.57	306
Kandiwala	90	4.67	420
Total ..	620		3760

Weighted average rainfall $= \frac{3760}{620} = 6$ inches.

Discharge$=640 \times \frac{1}{8} \times \frac{6 \cdot 0}{72} \times \sqrt{602} = 267$ cusecs.

Actual discharge $= 300$ cusecs.

Mr. S. I. Mahbub said that the main purpose of the paper appeared to be to evolve from first principles a formula for the maximum discharge from a flat highly cultivated catchment area, such as was commonly met with in the Punjab. The formula evolved was $Q=640\times I\times P+A^{\cdot 5}$. That appeared to be simply a modification of the Chamier's formula which using the same notation could be put down as $Q=640 \times I\times P\times A^{\cdot 75}$, the only difference thus being in the index of A.

The speaker said that the reason given by the authors for keeping the index of A as ·5 was, that "it was usually accepted as ·5." Surely that argument was not very impressive as no mention was made of the cases in which that value was accepted nor was a reference given to the observations, if any, on which that index of 0·5 was based.

To come to the next variable factor P, its value was obtained by the authors from the equation $P=\frac{R-D}{R} \times 100$.

The authors were of opinion that 20 per cent was a fair figure for the design of drainages, where catchment areas were similar to the one on which their calculations of P=20 was based. In making that statement they had unconsciously made the following assumptions :—

(*a*) That catchment areas of other drains would often be similar to that of the Sillanwali Drain.

(*b*) That the intensity curve for those catchment areas would be identically the same as the one they had drawn for the Lower Jhelum Canal.

(c) That the time taken by rain water to reach the drain from a point half way between the drain and the water-shed would always be 4 hours.

In those circumstances naturally, the value of P would be 20.

The question that the speaker would like to ask the authors was whether they had that figure of 20 per cent in their minds before they worked out the equation $P = \frac{R-D}{R} \times 100$. If so, they might re-examine their calculations for the figure of four hours which they had omitted to give in the paper.

That omission was extremely serious, as, if by any chance the authors had made a mistake in their calculations of time, and if the correct time for the Sillanwali catchment area was somewhere near 3 hours then from the authors' intensity curve, the intensity per hour would be 1" and the value of P would be 43 per cent. If however, the error was on the other side and the correct time was somewhere near 5 hours, the intensity curve would give an hourly intensity of about 0·57" and the value of P in that case would be zero.

The values of P and the index of A should not have been fixed in any arbitrary way as was done by the authors but should have been derived from the observed discharges of drainages in various circles, after bearing in mind the intensities in those particular tracts.

Taking into consideration the discharges of the drainages on the Lower Jhelum Canal, which corresponded with the rainfall assumed by the authors and making due allowance for higher intensities for periods less than 24 hours, it was found on plotting the values of C derived from those on a line showing the relationship between C and A for the Sillanwali Drain, that P=15 and index of A as ·6 suited better than P=20 and index of A as ·5 for the Lower Jhelum Canal at least.

Mr. S. L. Kumar said that the immense amount of work which the authors had put in the paper was obvious. They were to be commended as pioneers in this country in the determination of run-off from catchments by a rational method. The science was as yet in infancy in this country although a very valuable and vast amount of literature existed in other countries such as America.

The three papers *viz.*, "Rainfall characteristics, and their relation to soil and run-off" by C. S. Jarvis; "Formulas for rainfall intensities of long duration" by M. M. Bernard and "Rates of run-off and rational run-off formula," by Gregory and Arnold along with the discussions thereon which appeared in the Proceedings of the American Society of Civil Engineer in 1930 to 1932, constituted a big step forward in the development of the science.

The speaker further remarked that he had been faced with a problem of a similar nature in connection with the determination of waterways for a number of drainage lines which crossed the Lyallpur-Jaranwal Railway. The Irrigation Department were then providing 10′ wide and 1′ deep drains at those crossings. The catchment areas were determined and by use of the formulae mentioned by the authors in their paper a discharge varying between 7000 and 8000 cusecs was obtained whereas actually during one rainy season not a trickle flowed in the drain. As the demand of the officers of the Irrigation Department for waterway was excessive and the Railway Executive Engineer had no convincing figures to oppose their demand the result was a compromise. The Railway Department provided dips at those drainage crossings. Similarly a few years later, the speaker was ordered to determine the waterway required for bridges to replace dips on Wazirabad-Khanewal line. The observed figures of discharge over those dips, given by the Division, were none too reliable. The use of empirical formulæ gave results varying widely. Fortunately for all concerned, on account of financial stringency, the work was indefinitely postponed.

Supposing that the further detailed study of the subject of run-off from catchments showed that five per cent of the existing waterway on existing Railway bridges on the N. W. R. was superfluous (which estimate appeared to him to be on safe side) the elimination of that excessive waterway would make a considerable saving in the maintenance charges and also charges for strengthening and renewals of girders on bridges.

The speaker further remarked that it showed the great economic value of a suitable solution of that complex problem. It was suggested that on account of various, almost indeterminate factors which entered in the solution of that problem, a more concerted and planned effort should be made by the profession to solve it.

Coming to the paper itself the speaker said that he would inform the authors at the outset that his criticism of the paper was to indicate the defects in their assumptions and thereby to warn them against placing too much reliance on the results obtained by them, The speaker further said that the authors, while condemning the use of the empirical formulae quoted by them for Punjab plains and also while clearly stating the factors on which run-off depended, had themselves tacitly assumed that the discharge for the Punjab plains was proportional to $\sqrt{A}$ without adducing any evidence in its support. It might be mentioned that the Punjab Irrigation Department followed the formula $Q=C\sqrt{A}$ when C was a constant taken generally equal to 5 and A was the area of catchment in square miles. That formula in itself, was an empirical formula, which like others did not make any allowance for the shape of the area with respect to the external boundary and the internal arrangement of drainage lines, for the condition and slope of the main channel and for the gathering time of its small catchments. The correct value of run-off could only be obtained by varying C to vary with those factors and therefore its correct determination was almost impossible. The rational method, on the other hand, recognised the element of time in the computation of discharges from catchments and would ultimately supersede the empirical formula.

The speaker said that the authors while preferring the rational method fell unconsciously victims to the empirical formula, $Q=C\sqrt{A}$.

Actually the basic or fundamental equation for them to follow was $Q=P\times i\times A$, where Q was the discharge in cusecs, P= coefficient representing the ratio of the rate of rainfall, i=intensity of rainfall in cubic feet per second per acre or approximately in inches per hour, A=area of catchment in acres.

That fundamental relation required no proof. The authors on the other hand had used the formula $Q=Pi\sqrt{A}$ which was evidently wrong. In the formula $Q=C\sqrt{A}$, as already explained, C was a constant arbitrarily chosen considering the physical characteristics of the catchment and the usual intensities of rainfall and not a product of the two factors —the rate of run-off, C, and i, the average expected intensity of rainfall for the period of the concentration of the catchment.

It was not axiomatic, as the authors assumed, in that the maximum discharges occurred when the rainfall over the whole catchment lasted for the critical period or the concentration period of the catchment, as under those conditions all parts of the catchment would be contributing. It was generally a safe assumption but it was quite likely that the maximum discharge might occur as the result of an intense downpour on a considerable portion of the catchment particularly the area close to the outfall while the remaining areas away from the outfall yielded only a negligible run-off. The authors would have done well to work out a discharge on that basis also.

For the determination of run-off by the rational method the correct determination of the critical period or the concentration period of the catchment was very important as the value of 'i,' the expected average intensity of rainfall depended on it. It was generally given by the formula $i=\frac{K}{te}$, where t was the time. Thus i depended on critical period "t", which in its turn was determined by the average velocity of the water in travelling from the remotest portion of the water-shed to its outfall.

Thus $t= t_i - t_d$, where t_i was the inlet time, the time the water takes from the water-shed to the drain and t_d was the time the water takes from the upper end of the drain to the outfall.

The speaker further remarked that the authors considered 3 days as the critical period of Sillanwali drain catchment. Assuming with the authors that the average inlet time was 4 hours, the balance of 68 hours was taken by the water to cover 67 miles of the drain. That, considering the sections and slopes of the drain in Plate IV was much too high, the error being on the side of unsafety as the decrease in the value of t would mean a higher value of 'i' the average intensity of rainfall.

Unfortunately that error in determination of 'i' was further enhanced on account of the almost non-existence of hourly records of rainfall in this country. Excepting at a few important meteorological stations like Quetta and Bombay, the rainfall was recorded by ordinary gauges (and not by recording or automatic integrating gauges). There the rainfall was observed at some fixed time. It was thus quite possible that the precipitation of 3·5″ for one day assumed by the authors might have fallen in a single hour or even less and the two days' figure of 5inches in two hours one preceding and one following the time of observation. Similarly the 3 days' rainfall of 5·5″ might have fallen within 28 to 30 hours. The authors seemed to have ignored that possibility.

Although the authors admitted the non-existence of records of hourly intensities of rainfall, yet they had been able to draw a rainfall curve (*vide* Plate II) which showed crossmarks apparently indicating the recorded values of rainfall of short durations. It would be interesting to know how these values were obtained.

After having discussed the defects in the method of determination of 't', the speaker now criticised the author's method of determining P. It would appear to him that the authors started with a preconceived value of P equal to ·20, as their reasoning and the figures of losses they had accepted were defective.

P could either increase as 't' the critical period increased, remain constant as the authors had assumed, or decrease as 't' increased. Various authorities followed one of those assumptions or any other as could be seen on reference to current literature on the subject. The following statements were relevant to the determination of the value of P for those areas which were not completely saturated from the beginning of the storm.

(*a*) P increased directly with the urban development of the catchment, or in other words with the impervious surface. It would be effected by the physical characteristics such as vegetable cover, irregularities in the surface such as existed in cultivated fields, storage or pondage due to dowels. It might be mentioned that the authors had made no allowance for that factor, though they had allowed for absorption and evaporation losses.

(*b*) On account of increasing saturation, the value of P for the successive individual areas composing the catchment, increased with time.

(*c*) On account of the intensity of rainfall decreasing with time '*t*', the value of P for successive individual areas composing the catchment, decreased with time.

(*d*) With rainfall of considerable uniform intensity on any area and with definite physical characteristics and a definite degree of saturation, the value of P increased directly with the intensity of rainfall.

Thus by assuming a constant value of P for all parts of the catchment and for different values of critical periods the authors had unconsciously assumed that the increase in the value of P due to the increasing saturation of soil owing to continued rainfall, was offset by the corresponding decrease in the value of P due to the decrease in the average intensity of rainfall with larger values of '*t*.' That assumption was not justified.

The value of P should be actually determined by experiments conducted on catchments of various sizes. Tables should then be drawn up showing how P varied with '*t*' along with correction factors for shape and other physical characteristics.

The speaker further said that the authors' analysis for determining C rested on two assumptions.

(*i*) That the losses due to absorption and evaporation were ·57″ per hour as shown by Kennedy's experiments on an area half an acre near Chhanga Manga. That could not be considered a fair figure as the experiment was presumably conducted in dry atmospheric conditions and on a stagnant sheet of water probably with induced percolation due to head of water impounded. Further the results obtained on forest land could not apply to cultivated fields.

(*ii*) That the time taken by the rain water to reach the drain from a point half way between the drain and the water-shed was about 4 hours. Assuming that the time of 4 hours was correct (which could be shown to be incorrect) the authors deduced from the average hourly intensity of that period the loss per hour due to absorption. If that reasoning were followed to its logical conclusion then assuming any point from where the rain would take one hour to run to the drain, the hourly intensity from Plate II was 2·25 inches. The value of $P = \frac{2·25 - ·57}{2·25}$ $= 74\%$.

Similarly for elemental areas situated at 2 hours, 3 hours and 5 hours run respectively from the drain, P would be 59%, and zero % respectively.

Thus points from which the water took more than 5 hours would never be able to contribute anything to the run-off. That in itself showed the fallacy of the argument. The average run-off coefficient would then be weighted average on an area basis of those run-offs.

The authors had used the term "Critical Period" in two different senses in the paper. In the first place it was defined as the time for the rain water to travel from the extreme end of the catchment to the outlet or any point P on the drain. That was the correct use of the term. Other terms used to convey the same meaning were "period of concentration" or "period of total contribution." The critical period had also been taken to imply the time taken by the water to reach the drain. That was an incorrect use. The correct terms in current literature were initial or inlet time, gathering time or time of delay.

Mr. Kanwar Sain said that in the South-East of the Province, the Rural Sanitary Circle designed the drains on the basis of $1\frac{1}{2}$ cusecs per square mile of catchment area, assuming a run-off of $2\frac{1}{2}\%$ from a rainfall of 1 inch in 24 hours.

The actual discharge observed in 1933 in serveral drains was four or five times more than what was arrived at by the above assumption.

Though simple, that method on the very face was not rational. It was gratifying to see an attempt made in the paper for rationalising the method, as drainage was a very important subject.

The speaker remarked that the authors do not state their authority for the statement that the index n in $Q = KA^n$ was accepted as 0·5 for the Punjab plains. Some authorities had put down the following value

$$Q = 0·00786 \ KA^{\frac{3}{4}}$$

Values of K obtained from measurements of maximum run-off at a number of drainage projects in the Mississippi Valley ranged from

20 to 60. They corresponded to rainfalls of from 3 to 7 inches in 24 hours The measurements were made on areas varying from approximately 2 to 200 square miles.

The value of K depended primarily on the intensity and maximum duration of rainfall and all the other factors enumerated by the authors. One factor might be added to the list of the authors. Rain falling at night contributed more to the run-off than that falling in the daytime by reason of the higher evaporation in the latter case. A mild shower falling on a hot surface might be almost wholly evaporated.

A method more or less similar to the one arrived at by the authors from first principles was described by Talbot. He divided his catchment area longitudinally into reaches and from the slope of the country worked out the time taken to pass each reach and the total duration of storm for each reach. That was more or less the same as authors' critical time.

From the duration of storm, Talbot worked out his intensity of rainfall for that duration by his own formula which was $i = \frac{360}{30\,t}$, where i=intensity of rainfall in inches per hour during a duration of storm for t minutes.

Similar relations could be established for various regions of similar rainfall for the Punjab from the observed data.

The authors had made a slight arithmetical error. One inch rainfall per hour on one square mile comes to 645 cs. and not 640 cs. as stated by the authors.

Twenty per cent run-off arrived at by the authors for the Punjab plains looked to be on the heavy side. There would be more losses due to absorption, evaporation and transpiration by plants, when the water was in flow than when it was stationary, also the velocity of the prevailing wind at the time would affect such losses. Therefore Kennedy's experiment at Chhanga Manga was not a correct guide.

The above was simple enough, but the greatest difficulty was presented by the anomalous variations of the rainfall in India. At Rohtak, where the mean annual rainfall based on a record of 83 years was 18·37" there was a precipitation of 26·24 inches of rain in less than 30 hours on the 18th and 19th September, 1933. That high intensity of rainfall was unprecedented.

The speaker said that he would not enter into a discussion of the physico-geographical conditions which affected and determined it, the subject had been discussed ably and in great detail by Mr. Henry F. Blanford in the Indian Meteorological Memoirs Vol. III, but the fact remained that there were at any locality in Northern India seasons of widely prevailing scarcity as well as those of widely prevalent excess. What then, were the drains to be designed for? The speaker thought that it might be a better business proposition to allow the crops to suffer damage once in twenty years than to go to the expense of providing drainage adequately for the immediate removal of flood waters resulting from the severest storms.

Mr. B. L. Uppal said that the method described by the authors in working out the average rainfall of a big tract appeared to be satisfactory, although the area represented by a rain guage would be purely arbitrary.

The new formula for the discharge over a catchment area appeared to be as arbitrary as any other formula. The authors had given data for certain drainages and had tried to justify the high value of C in their formula $Q=C\sqrt{A}$ by remarking that "the first six have small catchment areas" and that "run-off from small catchments can be vey high. If they looked at the table they would find that even for those six drainages having small catchment areas, the coefficient varied from 26 to 204. Bagga inlet and Badshahpur syphon had about equal catchment areas, but still the coefficient for the former was 200, while for the latter it was 26 only. Naturally, the inference to be drawn was that either the formula was wrong or the maximum discharges shown were hopelessly wrong. Probably it was the latter. The authors had not mentioned how and by whom those actual discharges were observed. It was not uncommon that for a syphon, the discharge was calculated from maximum gauges observed above and below the syphon and the chances were that those gauges or flood marks were unreliable and that in working out the discharge through the syphon, no account was taken of the silted sectional area of the barrel.

As regards the design of the section of a drain, it was of the utmost importance to see that the section was suitable for passing small and big discharges. If a drain was designed for the maximum discharge and actually a much smaller discharge was received by it, one had only to expect that the drain would silt up gradually and would become less effective.

The drainages or the outfall channels of the siphons on the Upper Jhelum Canal were designed for the maximum theoretical discharges. In most cases the inlets had sandy beds with steep slopes. The result was that the barrels as well as the outfall channels were silted up. In two cases, the remedy of contracting the outfall channel so as to make it fit to carry small discharges proved so useful that the silted barrel of the syphon became clear. Thus theoretically the section of a drainage should be V shaped. It would serve equally well, if a small gullet was made in the bed of the drain having 2 to 4 feet bed width,

Mr. Duncan said that it would interest the members of the Congress to hear some actual figures of discharges passed in the drains in the jurisdiction of the Drainage Sub-Division of the Lower Chenab Canal (West) Circle, the greater part of which lies in the Hafizabad Tehsil of Gujranwala District.

The drains in the Sub-Division, mostly seepage-cum-stormwater were the only channels in it and their maintenance, the only work which the staff had usually to do. Daily gauges were read at various points on the drains and monthly discharges observed. In the monsoon, as many flood discharges were taken as were possible. Some reliance could, therefore, be put on the data obtained.

A graph had been made from 17 discharges observed on the Ahmadpur Kot Nikka Drain at R. D 1,98,000 in 1933 and 1934 and the daily monsoon discharges taken therefrom. Tabulated daily data for the maximum flood periods as well as abstracted data for the monsoon stages were appended. It would be seen that the discharge on 19th August was 222 cusecs, rose to 1500 on the 22nd and gradually fell to 344 on 1st September. The total run-off in the drain from 18th August till 1st September was 27% of the weighted average rainfall, 11·34 inches during that period, which was taken from the five stations in the catchment area of 156 square miles. This gave a maximum discharge of 10 cusecs per square mile.

A similar observed discharge of 1400 cusecs was obtained for the same site on 8th July 1934 from a rainfall of weighted average 3·87 inches occurring some time between 8 hours on the 7th and 8 hours on the 8th. The discharge rose form 72 cusecs on the 7th to 1400 on the 8th and fell to 48 on the 14th.

Some relevant data was then given :—

1. Mean slope R.D. 0 to 1,98,800 .. ..1 in 3460
2. Mean slope of N. S. taken in a straight line from R. D. 0 to 1;98,800. 1 in 2600
3. Average depth of spring level in vicinity of drain below N. S. R. D. 0 to 1,98,800 in December, 1934. 2·3 feet.
4. Average depth in December, 1934 of silted bed below N. S. R. D. 0 to 1,98,800. 3·3 feet.
5. Total length of branch drains from R. D. 0 to 1,98,800 29 miles.

Similar high discharges were obtained on 1933 in the Ahmadpur Vagh Drain which started just downstream of Ahmadpur syphon and received through the syphon the run-off from a tract of practically undeveloped area in the Gujranwala District of estimated catchment area 376 square miles.

From R. D. 0 to 85,000 of the drain the catchment area was 137 square miles and the total length of branch drains in the same reach was 20 miles in 1933. Unfortunately the heavy monsoon of 1933 breached the banks in numerous places such that the resulting discharges in the drain were less than they otherwise would have been. Even then the maximum flood level was 4 feet above the N. S. at R. D. 85,000 and the flood remained above the N. S. for 15 days on end. The discharges at R. D. 85,000 were calculated from observed velocities and cross sectional areas and 30% was added when the W. S. L. was above the N. S. to represent the discharge outside the drain. This percentage was probably much too small.

After deducting the daily discharges of the Ahmadpur syphon (which were obtained from a graph of 14 observed discharges) the nett discharges at R. D. 85,000 were as follows :—

12th August 1933 nil, 17th 400 cusecs from which date the nett discharge rose steadily to 1010 on the 22nd and thereafter fell steadily to 370 on the 31st. The weighted average rainfall from 12th to 31st was 10·0 inches and the nett maximum discharge in the drain at R. D. 85,000 was 7·4 cusecs per square mile.

Due to the breaches mentioned above the maximum discharge per square mile must have been more than 7·4 cusecs. The estimated total run-off in the rain at R. D. 85,000 from 12th to 31st was 28% of the rainfall; and if the 30% referred to above were not added it would be 18%.

The speaker observed that in both tracts the spring level was high and much of the land was affected with Kallar.

A tract of land lying between the Lower Chenab Canal, Upper Chenab Canal, Nokhar Branch and Nurpur Distributary of estimated area 376 square miles had its outfall at the Ahmadpur syphon. As far as the speaker knew the only stormwater drain in the tract was the Pandoki Harkarn Drain of length just under 14 miles which lay for the most part within half a mile of the Lower Chenab Canal and had its outfall at Ahmadpur syphon.

A graph showing the discharge against downstream gauge had been made for the syphon from 14 observed discharges and the data of discharges for 1933 was appended. It would be seen that the maximum discharge of 700 cusecs passed on 21st August, giving almost 2 cusecs per square mile and that the flood was sustained at 1 cusec per square mile or more for about 10 days on end. At a distance of 2 miles downstream of the syphon there was another syphon, the Kot Nikka, whose sectional area of 36 square feet was quite inadequate to pass off a flood quickly. It was therefore probable that higher discharges at the Ahmadpur syphon would have otherwise obtained.

The Shori Drain is a tributary of the Ahmadpur Vagh Drain and of a catchment area of 8·7 square miles. The maximum discharge observed near the outfall in 1933 was 444 cusecs on 17th July with gauge 4·6. On 21st August the gauge rose to 5·3 and this represented about 500 cusecs. Taking the area as 9 square miles, this gave 56 cusecs per square mile, which was the maximum run-off per square mile recorded for 1933 in the Drainage Sub-Division.

By taking the data of maximum discharges for the Ahmadpur Kot Nikka Drain at R. D. 1,98,800 and the Shori drain, an empirical formula could be derived as follows :—

$$Q = K\,A^{N}$$

For A.K.N. Drain $Q = 1560,\ A = 156$

For Shori Drain $Q = 500,\ A = 9$

which gave $Q = 207\ A^{0\cdot4}$

where Q was probable maximum discharge in cusecs, and A was the catchment area in square miles.

The speaker continued that this rough and ready expression could serve as a guide locally ; nothing could be said about its use elsewhere.

Commenting on the author's formula $Q=640 \times I \times P \times \sqrt{A}$., Mr. Duncan said that the authors had estimated that the time taken for rain to reach the drain from a point midway between the watershed and the drain was 4 hours and taking the maximum intensity for a 4-hours' storm as 0·70 inches per hour and the absorption as 0·57 inches per hour had deduced that nearly 20% of the whole rain between the drain and watershed reached the drain. It seemed to the speaker, however, that accepting the above intensity 0·70 and absorption 0·57, rain which took more than 5 hours to travel the distance to the drain would not reach it, due to being absorbed in the hour immediately after the end of the storm.

The depth of rain on the ground gradually increased at the rate (0·70 —0·57) inches per hour and after 4 hours the depth was 0·52 inches. The rain would then stop and absorption continue at 0·57 inches per hour ; hence the accrued depth of 0·52 inches would be absorbed within one hour. It appeared then that a four hours' storm would give a much smaller percentage run-off than 20% accepting an absorption of 0·57 inches per hour. If, however, a smaller period of greater intensity was taken then the percentage run-off would greatly increase. The maximum intensity for a one hour's storm was 2·3 inches per hour (from Plate II) and all rain left on the ground would be absorbed in about 3 hours after the end of the storm. The maximum intensity for one-half hour was shown as about 4 inches per hour but the chances of such an intensity obtaining over a large area were remote.

The authors have applied a factor '*i*' called the Critical Intensity along with the percentage of run-off "P" but there seemed to the speaker no reason for it at all, except as a flattening factor. The authors stated that a maximum flood would occur at any point on the drain when the flood from the head reached the point at the same time as the local flood. This postulated that the storm travelled in the direction of the drain with roughly the velocity of the water in the drain. Disregarding flattening, the discharge in the drain would increase with the length of the drain as long as the intensity of rain remained constant; and the duration of the flood at any point on the drain would be constant and equal to the duration of the flow from the catchment into the drain at any section.

Flattening, however, did occur and reduced the discharge and lengthened the duration of the flood, but how exactly it did so was a question. There seemed no valid reason for using the Critical Intensity as a flattening factor.

DATA OF DISCHARGES PASSING AHMADPUR SYPHON

AT R.D. 1,28,000 LOWER CHENAB CANAL.

Estimated Catchment Area 376 *Square Miles* (*Undeveloped*).

	Period.	15 July to 11 Aug.	12 Aug. to 31 Aug.	1 Sept. to 30 Sept.	Grand Total.
1933	Total Daily discharges (Cusecs).	2,750	6,980	3,920	13,650
	Weighted Average rainfall (inches).	9·93	10·0	3·51	23·44
	Rainfall (Acre-feet) ..	1,98,000	2,01,000	7,01,000	4,69,100
	Total discharges as percentage of rainfall.	3	7	11	6

N. B. (1) Rainfall taken as same as that for Ahmadpur-Vagh tract.

(2) Discharges are taken from graph made from 14 observed discharges.

MAXIMUM DISCHARGES.

	August.	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1933	Discharge (cusecs).	200	160	240	400	360	320	340	400	600	700	600	550	400	320	220

AHMADPUR KOT NIKKA DRAIN. DISCHARGE DATA.

Catchment Area up to R. D. 1,98,800 is 156 Square Miles.

	Date.	Aug. 18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sept. 1	Total.	15 July to 11 Aug.	12 Aug. to 31 Aug.	1 Sept. to 30 Sept.
1933	Discharge R.D. 1,98,800 (cusecs).	202	222	654	1,440	1,550	1,440	1,340	1,240	980	980	710	600	544	454	344	12,700=25,400 Acre-Feet.	5,842 Acre-ft.	26,476 Acre-ft.	11,714 Acre-ft.
	Weighted average rainfall (inches).	0.38	1.18	1.71	4.13	1.88	1.61	..	..	..	..	0.33	0.06	..	..	0.06	11.34	8.9	13.2	1.8
	Rainfall in acre-feet																94,000	74,100	1,10,000	15,000
	Total Discharges expressed as percentage of rainfall																27	8	24	78

MAXIMUM DISCHARGE PER SQUARE MILE IS 10 CUSECS.

	Date.	July 7	8	9	10	11	12	13	14	Total 8 July to 14 July.	1 July to 31 July.	1 Aug. to 31 Aug.
1934	Discharge R. D. 1,98,800 (cusecs)	72	1,400	770	454	222	134	85	48	3,113=6226 Acre-Feet	7,370 Acre-ft.	4,436 Acre-ft.
	Weighted average rainfall (inches)	..	3.87	0.16	..	..	..	..	..	4.03	4.6	6.9
	Rainfall in Acre-Feet									33,600	38,400	57,500
	Total Discharges expressed as percentage of rainfall.									19	19	8

N.B.—(1) Rainfall for any date is that in period of 24 hours previous to 8 hours on that date.

(2) Weighted average rainfall is that of 5 stations.

(3) Discharges are taken from graph made from 17 observed discharges.

(4) Cusec-day is taken as 2 acre-feet.

Replying to Mr. S. I. Mahbub, **Mr. Khangar** said, that the index n accepted for the Punjab plains was usually 0·5. The formula used by the Urban Sanitary Board was $Q=75\sqrt{A}$. The drainages in the Gujrat Division were designed with the formula $Q=0{\cdot}5\sqrt{A}$. As pointed out in the introductory remarks, the index n depened on the synchronisation of rainfall. If the catchment area was small, synchronisation of rainfall could be complete and the index n would be unity. As the catchment area increased, the index n would decrease. How it should vary, only further experience could show.

As regards the value of P, the authors did not recommend 20% to be used blindly in all cases. They had indicated the method as to how it could be determined. If the inlet time was not 4 hours, or absorption loss different than assumed, the value of P would certainly vary.

As Mr. Mahbub had not supplied any curves, his argument, that n would be different from 0·5 could not be put to test. (He promised to supply the curves but has not done so far.)

Replying to Mr. Kumar, Mr. Khangar said that Mr. Kumar's state ment that the formula should be $Q=P\,I\,A$ was not correct, because the rainfall did not cover the whole catchment area at the same time. Some parts of the catchment area would be unaffected, and would not be contributing. Some sort of index to A had therefore to be applied.

In reply to the objection that the discharge for smaller areas ought to have been worked out, the author said that Mr. Kumar himself admitted that the assumption made was safe. In any case the discharge from small areas would last for a very small time.

As regards the objection to accepting the critical period of 3 days for 67 miles length of the drain, Mr. Khangar explained that the velocity of 1 mile an hour was a correct assumption. When channels were opened after a canal closure, the water travelled at a velocity of about $1\frac{1}{4}$ to $1\frac{1}{2}$ miles per hour. In a drain the velocity would not be much over one mile an hour.

The possibility that rainfall assumed for 24 hours, would fall in a shorter time had not been ignored. Unfortunately no records were available. Until more data was collected, one had to base all work on the facts known.

Mr. Khangar denied that atmospheric conditions would have much effect on the total loss due to absorption and evaporation. This loss depended more on the nature of the soil than on anything else. Kennedy's experiments proved that loss due to evaporation was $\frac{1}{100}''$ per hour which was negligible.

Mr. Khangar accepted Mr. Kumar's conclusions that from the portion that was near the drain, more water would be contributed than from the distant areas. Some of the portion would be ineffective. The percentage of run off calculated for a point half way between the drain and the watershed would not be an unfair figure for the whole area.

Replying to Mr. Kanwar Sain, Mr. Khangar said that he had already dealt with Mr. Kanwar Sain's points. He explained that the formula $Q=0{\cdot}00786\ KA^{\frac{3}{4}}$ put forward by Mr. Kanwar Sain was wrong.

Taking $K=60$, and $A=1$ sq. mile, the discharge works out to $Q= {\cdot}00786 \times 60 = {\cdot}4716$ cusecs. This was evidently wrong. He admitted that the figure pointed out by Mr. Kanwar Sain should be 645 and not 640, but the mistake did not matter much.

Replying to Mr. Uppal, Mr. Khangar said that he could not vouch for the accuracy of the observation of discharges but as those were obtained from old official records, they were accepted for what they were worth.

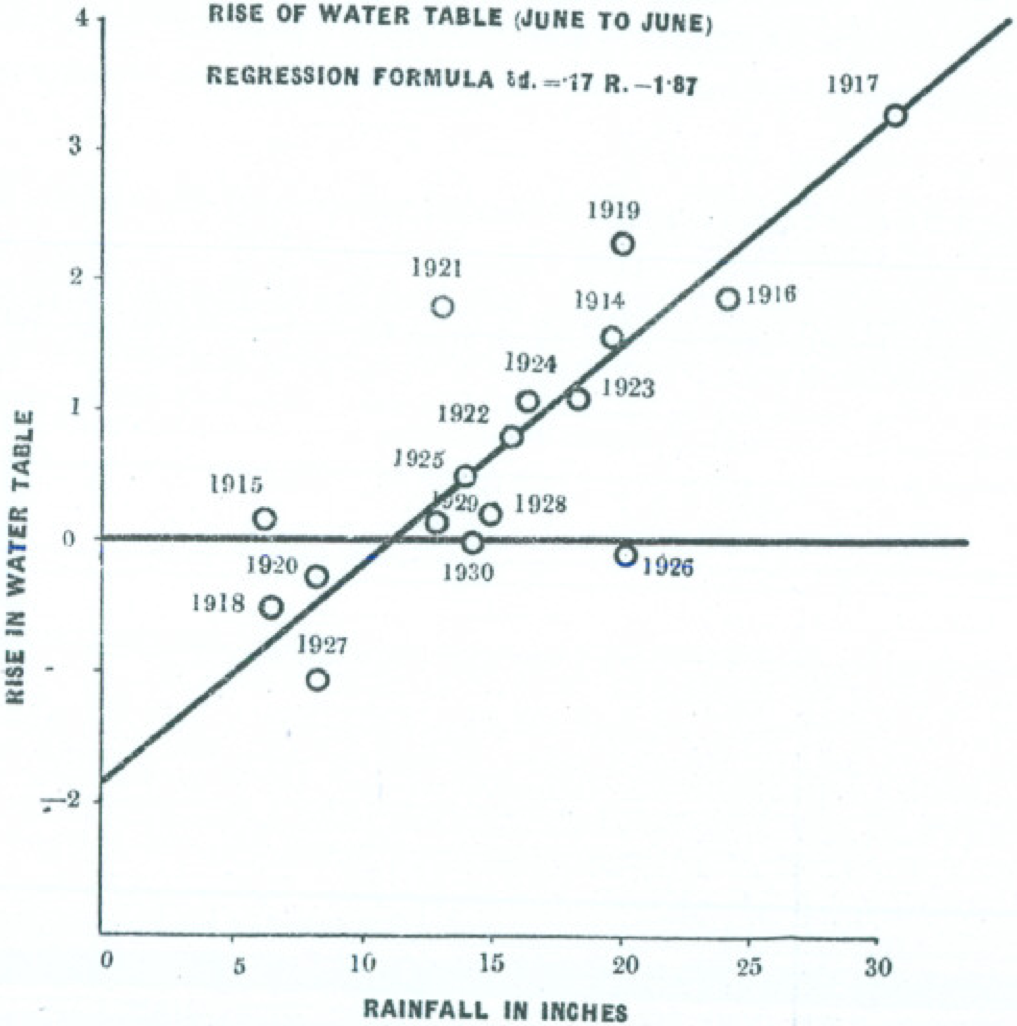
Replying to Mr. Duncan, Mr. Khangar said that Mr. Duncan had given some figures for high discharges. He doubted whether any accuracy could be attached to Mr. Duncan's formula $Q=207\ A\ 0{\cdot}4$ which was based on only two observations. The correct formula could only be obtained by taking a very large number of observations and plotting curves.

U. C. C.

PLATE VII

1914–1930

RAINFALL (JULY—SEPTEMBER)



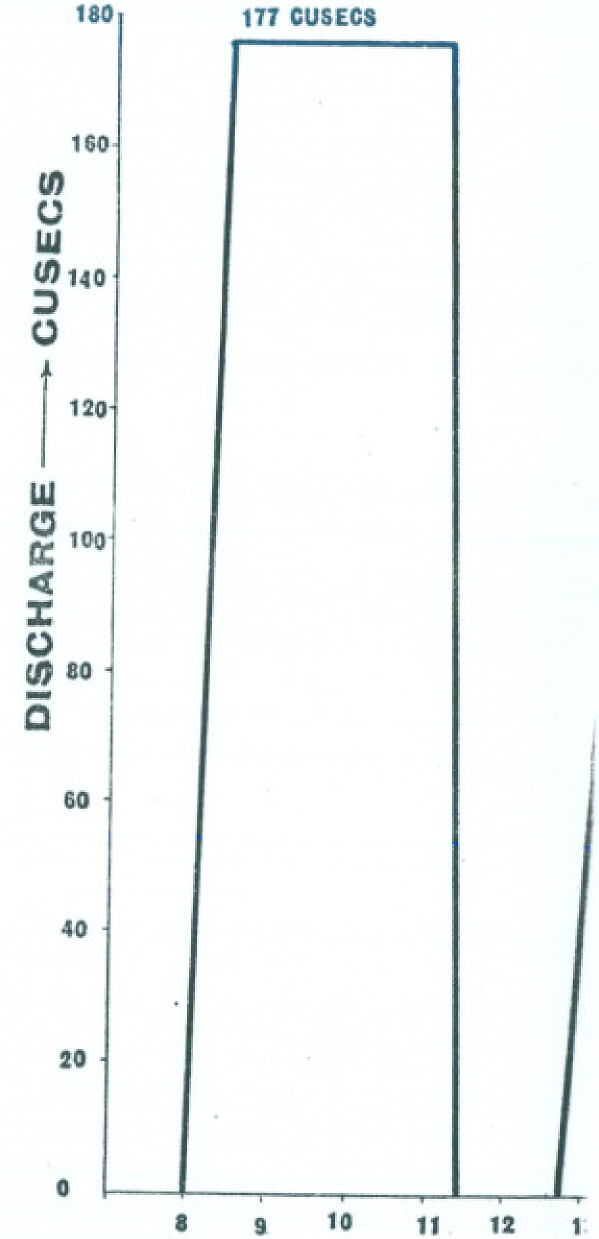
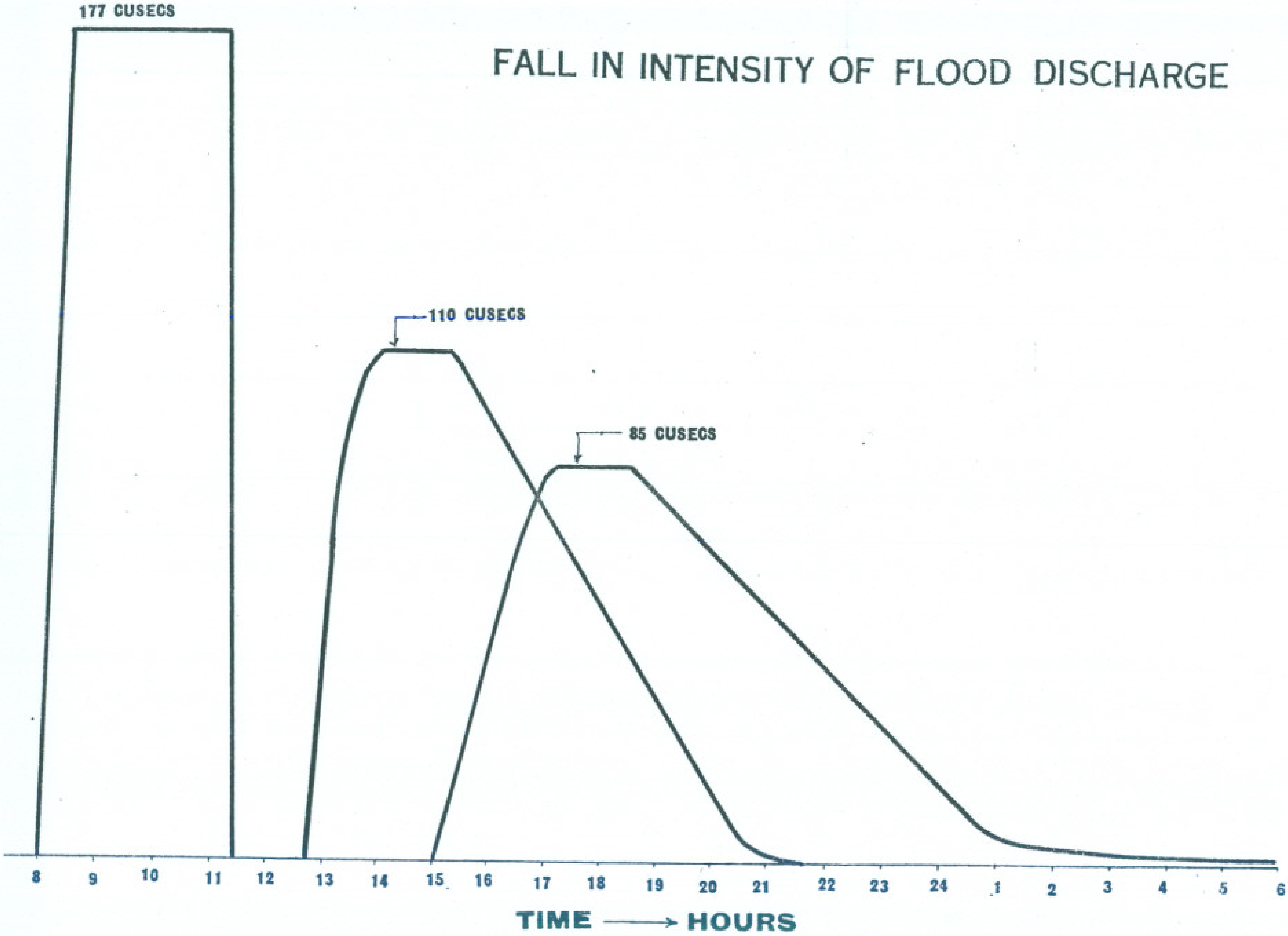


PLATE V

FALL IN INTENSITY OF FLOOD DISCHARGE



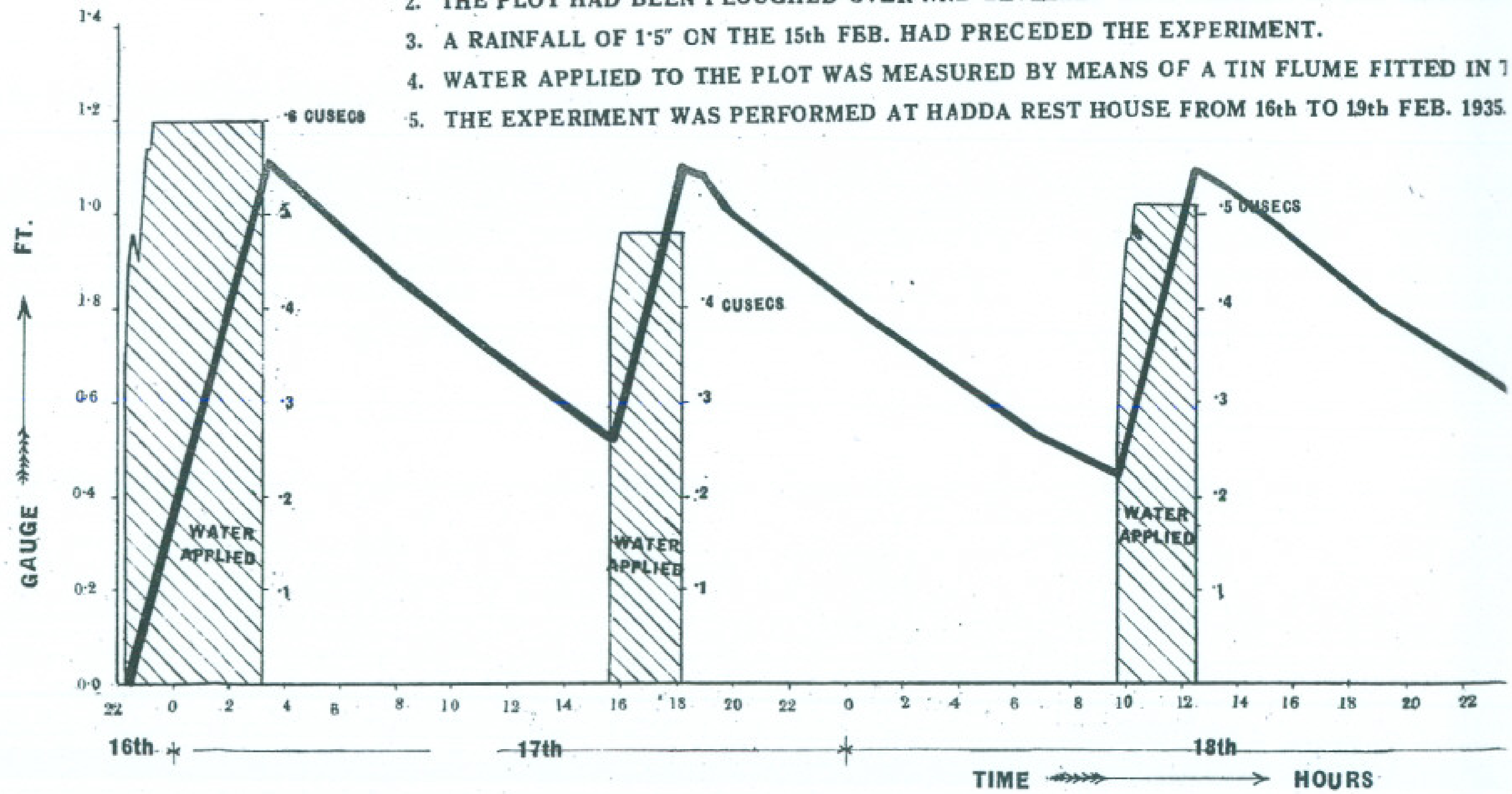
RESULTS

OF

AN EXPERIMENT TO DETERMINE THE AMOUNT OF W
ABSORBED BY THE SOIL

DETAILS

1. SIZE OF THE PLOT UNDER BXPERIMENT WAS 80·8′ × 59·8′ = 4832 Sq. Ft.
2. THE PLOT HAD BEEN PLOUGHED OVER AND LEVELLED BY A SOHAGA. IT HAD BEEN LY
3. A RAINFALL OF 1·5″ ON THE 15th FEB. HAD PRECEDED THE EXPERIMENT.
4. WATER APPLIED TO THE PLOT WAS MEASURED BY MEANS OF A TIN FLUME FITTED IN T
5. THE EXPERIMENT WAS PERFORMED AT HADDA REST HOUSE FROM 16th TO 19th FEB. 1935.



RESULTS

OF

AN EXPERIMENT TO DETERMINE THE AMOUNT OF WATER ABSORBED BY THE SOIL

PLATE VI

:XPERIMENT WAS 80·8′ × 59·8′ = 4832 Sq. Ft.

;HED OVER AND LEVELLED BY A SOHAGA. IT HAD BEEN LYING FALLOW FOR THREE MONTHS. NO CROP OR VEGETATION EXISTED.

15th FEB. HAD PRECEDED THE EXPERIMENT.

.OT WAS MEASURED BY MEANS OF A TIN FLUME FITTED IN THE WATER COURSE NEAR THE PLOT.

FORMED AT HADDA REST HOUSE FROM 16th TO 19th FEB. 1935.