PAPER No. 134.

HYDRAULIC OBSERVATIONS ON THE SHYOK FLOOD OF 1929.

By J. P. Gunn.

Early in 1929 it fell to my lot to go to Ladakh and investigate the glacier dam that had formed on the Shyok river ; one of the objects of the expedition was to ascertain, if possible, what would be the effect near Attock of water released by the bursting of the dam.

On the way up to the dam I investigated the traces left by the flood of 1926 and tried to work out something whereby an approximate prediction might be possible.

I inspected the dam from below and then made a detour and got up to the lake. After the survey of the lake had been done the dam burst, and on the return journey I made such observations as were possible of the flood marks at various places. These observations differed widely from what I expected and it is for this reason that I put forward this paper.

Some of the assumptions made in it are bold in the extreme, while the prediction curves are nothing more or less than arguing from the particular to the general, but I can see no other method of dealing with the question. All I can hope is that this struggle to produce results, with insufficient knowledge of the nature of turbulent flow of water, and unreliable data, may inspire some one to carry out investigations to clear up some of the problems set out for consideration.

Shyok river.

To enable the nature of the Shyok river bed to be appreciated I have given longitudinal sections at Sasir Brangsa and from Sati to Diskit and a rough plane table sketch of the course of the river in the latter reach in plates II to IV. The points at which the 1926 flood levels were observed along with their values are shown on the plane table sketch, the underlined values show the 1929 flood levels.

The cross sections at the gauge site, plate V, were taken along a line which I anticipated would be at right angles to the direction of the current during floods. I selected a site on the left bank above Khalsar for the gauge where a cliff rose straight out of the water. From our information it seemed that the water surface here was more or less level in the 1926 flood, but this year's flood which gave 28 feet cross slope at this point shows that either the nature of the flow was different or that our original information was incorrect. The latter is probably the case as no flood marks could be seen on the rock. The local inhabitant had no interest in that particular spot and probably drew on his imagination.

As can be seen from the cross sections, plate V, the river during the flood scoured its bed about nine and a half feet at the site of the gauge and concentrated the flow into one channel.

In the reach from Sati to Diskit the general slope of the water surface over a distance of about twelve miles is 3·75 feet per thousand feet or 18·75 feet per canal mile of 5,000 feet. In the upper reach above Sasir Brangsa the slope over about six miles is 8·20 feet per thousand feet or 41 feet per canal mile, while in one reach it drops fifty feet in half a mile. These mean slopes of 3·75 feet and 8·20 feet per thousand feet have been adopted in the calculations of discharges.

Cross sections of the Shyok between Sati and Diskit are reproduced on plates VI and VII as an indication of the general nature of the bed and explain why the seemingly open bed at the Shyok-Nubra confluence has such a slight effect on the flow.

The flow in floods is extremely turbulent and influenced largely by local conditions. I have therefore not attempted to draw a longitudinal section to show the high flood levels but have indicated the position of observed points with their values. It will be seen from the sketch on plate IV that the floods of 1926 and 1929 varied greatly in height over a comparatively short distance.

Flood levels.

Taking the right bank of the river, where the marks of the 1929 flood were in general better defined, half a mile above the gauge the 1929 flood was 18 feet higher than that of 1926, at the gauge it was only 8·47 feet higher, while six miles further down in the region of Thirit differences of 46·2 feet and 47·19 feet were observed ; as the levels were followed up the Nubra towards Teggur the difference gradually fell off to 16·48 feet.

It will be seen from these figures that it is impossible to compare the magnitude of any two floods by a comparison of their maximum levels observed at any one place. Without some such observations it is almost impossible to conceive the irregularity of flow that occurs during floods, and I am of the opinion that no gauge set up in the Shyok can give a quantitative prediction of the effect at Attock.

Flood travel.

The rate of travel of the floods of 1926 and 1929 is given in the table below. The distances have been scaled off the latest available $\frac{1}{4}$" maps while the times have been obtained by local enquiry and can only be taken as approximate. The same information is plotted on plate VIII and shows a fairly satisfactory agreement between the data. This plate also shows the mean velocities and velocities as calculated in table 3 for certain points. The actual times from the warning gauge at Khalsar to Attock were approximately fifty-six hours for the 1926 flood and fifty-nine hours for the 1929 flood.

Table 1.

Serial No.	Particulars.	No. of miles (distance travelled).	No. of hours.	Velocity in miles per hour.	Velocity in feet per second.	Mean velocity in feet per second.
	Flood 1929.					
1	Sasir Brangsa to Khalsar	130	22	5·91	8·67	12 31
2	Khalsar to Skardu ..	165	16	10·31	15·12	
3	Skardu to Bunji ..	96	14	6·857	10·06	
4	Bunji to Attock ..	289	29	9·965	14·62	
		680	81			
5	Attock to Kalabagh ..	99	8½	11·65	17·08	
	Flood 1926.					
1	Diskit to Skardu ..	153	16	9 56	14·03	14·47
2	Skardu to Bunji ..	96	8	12·0	17·60	
3	Bunji to Chilas ..	47	5½	8·55	12·53	
4	Chilas to Attock ..	242	25	9·68	14·20	
		538	54½			

Gapshan Lake.

It is not practicable to reproduce the map of the lake to original scale, but plate IX shows a reduced map on a scale of 1" to a mile as surveyed. The contours can not be reproduced but the lines on which soundings were taken are shown together with the level of the bottom, plate X shows the area at each contour plotted as a curve and the table shows the actual areas together with the volumes between successive contours and the total volume up to any contour, this last quantity is also shown on the diagram as a curve.

From observations taken during our stay at the lake we found the total rise, which was nearly uniform, was 5·9 feet in 211 hours giving a daily inflow of 6,581 foot-acres per day. The total volume in the lake was 1,095,500 foot-acres.

To get an approximation to the rate of inflow in a year I made certain assumptions. I had taken that the burst in 1926 occurred late and that there would be no more melting that year, or rather that the dam reformed before the melting in 1927 began, and that there was no water left after the 1926 burst. Also I neglected evaporation and absorption and assumed that the water in the lake was the result of three years' melting. This gave an average annual inflow of 365,000 foot-acres.

To check these assumptions I referred to Mr. Ludlow who stated that, at the time of his visit in 1928, a slight fall of snow occurred on the first night he reached the lake and that the next two days were abnormally hot; he considered that the inflow was probably above the normal; his estimate of the rate of rise was about $1\frac{1}{2}$ foot per day for the two days he was there. It was almost exactly a year later that we visited the lake so that at the time of Mr. Ludlow's previous visit the volume in the lake would probably be 730,000 foot-acres. From the curves this gives the level of the water as 15,850 and the area about 7,300 acres. This gives a rise of 0·9 feet per day for normal inflow. Considering the difficulty of estimating a rise in water level, and the light snowfall followed by abnormal heat, I consider that we may accept the figures and presume that the assumptions are correct.

To get some idea of the variation in the rate of inflow I have based an estimate on the discharge of the river at Khalsar. The river above Khalsar is almost enirely glacier fed but in the early part of the year much water will come from the snow melting. As the flood scoured the bed down low at the gauge site the discharges for a whole year are not available. I have however plotted on plate XI a curve of the monthly mean maximum temperatures at Leh and Dras, both a mean of years and this year's mean, and also on the same time scale a curve of discharges at Khalsar. By assuming that the general shape of the discharge curve will conform to the temperature curve, I have taken the mean daily discharge for each month at Khalsar and assumed that the inflow into the lake occurred in the same proportion. The results are given in the table below, from which it is possible to forecast roughly what the level of the water in the lake will be in any month when one observation of the water level is available in any year.

Table. 2.

Month.	Assumed discharge at Khalsar, cusecs.	Assumed monthly inflow at Lake, foot-acres.
June	1,000	5,183
July	22,000	114,610
August	35,000	182,500
September	12,000	62,514

Attock gauge.

As the main object of the expedition was to ascertain the probable effect at Attock of a flood from the Shyok, I devoted some time to trying to get a calibration curve for the Khairabad gauge situated a mile and a half above Attock Bridge. The only data available from which this could be done were the daily discharges observed at Kalabagh a hundred miles below Attock. These observations are made with current meters, observing the mean velocity in low supplies and surface velocities in high supplies,

while surface floats are used when the discharge is very big and velocities too high to enable a boat at anchor to remain steady.

Owing to the river bed at Attock silting and scouring it was not possible to get any results from points that were not selected with care, but after allowing for time-lag and selecting points when the river discharge was steady and conditions generally indicating no abnormal silt I derived the formula—

$$\log Q = 0{\cdot}805 \log G + 4{\cdot}3014$$

for Khairabad. The range of observations for which this appeared to hold is between gauges of 5 feet and 30 feet with discharges of 70,000 cusecs and 300,000 cusecs respectively. From this I plotted a time-discharge curve from the observations available, plate XII, for Khairabad.

I also endeavoured to find a similar relation for the Attock Bridge gauge but the channel section is not so uniform there and I could get no satisfactory curve.

Like all empirical formulae this discharge equation needs to be applied with care and can only be expected to hold for a certain state of the river.

The Indus had been running with a discharge of 200,000 to 300,000 cusecs from the middle of July and had reached over 400,000 cusecs on the 2nd August at Kalabagh falling to 200,000 on the 11th and had only increased slightly to 237,000 on the 17th, from which one would expect a certain amount of silt to have been deposited and not removed up to the 17th by the gradual rise of the river. That this discharge is below the formula discharge was only to be expected. The deposit however would readily be moved by the rapidly rising flood and I have adopted the formula discharges for the rising river and peak discharges. On the falling river silt must again have deposited, and so long as the formula gave a fairly uniform rate of fall in discharge I have adopted these discharges; but from 8 A. M. on the 20th I have adopted lower discharges following approximately the same rate of fall, as the comparatively sudden change in slope of the curve indicated that silt was depositing.

I have taken as the Indus component of this flood 237,000 cusecs as that discharge was measured at Kalabagh on the 17th and 22nd and brought the time-discharge curve for Attock to this value on the 21st to allow for time-lag. There was little rain during the 19th and 20th anywhere in the Indus Valley but after the 21st a gradual rise set in and perhaps the discharge on the closing day gives the Indus credit of a slightly larger quantity of water than it should.

Treated by this method, however, the total run-off in three days at Attock due to the Shyok dam bursting comes to 884,300 foot-acres as compared with 1,095,500 foot-acres in the lake. In the case of the similar flood in 1926 approximately 10 per cent. of the total run-off, as ascertained from the records of the Discharge Division, occurred after

the third day, but in the case of this flood the river started to rise due to rain and no proper account can be kept of the Indus component after the third day. The agreement between the calculated run-off at Attock and the quantity in the lake is reasonably close and would show that the formula gives reasonably close results for flood peaks, and the extension of the formula beyond the range of observations seems justified.

The only way which I see of making any estimate of the effect at Attock of a burst in the Shyok dam depends on the use of this discharge diagram. From the diagram it appears that aproximately a quarter of the total volume in the lake passed Attock with a fairly uniform discharge in twelve hours. The dotted lines show the twelve hours interval, and from this it would appear, possible to estimate the Attock discharge from the volume of the lake within reasonable limits.

The following method was adopted in preparing a diagram for predicting the heights to which a flood from the Shyok dam might raise Attock Gauge. One quarter of the total volume of the lake is presumed to pass Attock at a uniform gauge in twelve hours as that is what the time discharge curve for this flood shows, that is, one quarter of the volume in foot-acres gives the discharge at Attock in cusecs.

It is also assumed that, no matter what the amount of silt in the bed of the river before a flood is, in high flood the silt is scoured out and the formula gives the discharge passing. The standard discharge for various gauges at Attock was then calculated, to these were added successively the expected flood discharges from the lake and the corresponding gauges calculated. To allow for the effect of local heading up a margin of five feet was added to the calculated gauges. Then taking the gauges before the flood as abscissae and the maximum flood gauge as ordinates curves for each depth of water in the lake were drawn. See plate XIII.

To allow for the probable departure from the standard formula discharge three more scales are shown. These correspond to states of the river when two, four and six feet gauge above the standard are required to give the formula discharge. The Executive Engineer, Discharge Division, can tell at any time which scale should be employed.

The method of using the curve is simple. On being informed which scale of abscissae is to be used, the intersection of the ordinate through the gauge reading of the day and the curve of lake level gives the height to which the Attock Gauge may be expected to rise.

I do not consider this method of flood prediction very satisfactory owing to the vast number of uncertain factors involved but at least it will give some guide. Also as the level of lake this year was within a small distance of the maximum traceable lake level it is unlikely that a greater effect will ever occur at Attock.

Hydraulic Formulæ.

The following paragraphs deal with certain aspects of turbulent flow and give some guides for experimental investigations that may be valuable where not actual flood levels, but volumes passed, are under consideration.

With a view to ascertaining, if possible, how far the formulae for smooth flow could be adapted to flood conditions by a modification of the constants, I examined such data as were available at various sites and made use of the fact that the volume in the lake was known.

The data for the upper reaches of the Shyok are unsatisfactory from the point of view of any great accuracy but even then they give valuable indications.

At Sasir Brangsa it was possible to obtain fairly satisfactory cross sections as the ice had left berms at various points, but the man, who is stationed there to conduct caravan across the ford, could not give any reasonable idea of the times at which these levels occurred. On the 18th he stated originally that the dam had broken on the 14th instead of the 15th, and I am very doubtful altogether of the times at which he states the levels occurred.

At Khalsar the times were probably more or less accurate as far as could be judged but only levels on the left bank at the gauge could be got with any accuracy as no marks were visible on the right bank.

At Skardu levels were read off the gauge and times taken with a watch but as the gauge was washed away the rate of fall below 25 feet is conjectural.

Unsatisfactory as these data are, the results of calculations indicate that the conventional co-efficients in the usual formulae are far from correct for turbulent flow such as occurs in floods.

The method of examining the data was based on Manning's formula $V = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}} R^{\frac{2}{3}}$ in which n has the same value as in Kutter's ormula. I assumed that the portion $\frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$ remained constant for each site throughout the flood. Then from the observed cross sections shown in plates V, XIV, XV, the area and hydraulic mean radius were calculated for each stage. The Attock and Kalabagh data were given by this discharge division.

The discharge for each stage is given by—

$$Q = A \times R^{\frac{2}{3}} \times \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}} = K A R^{\frac{2}{3}} \text{ say.}$$

Plotting the quantity $A. R.^{\frac{2}{3}}$ as ordinate on a time basis the area of the curve when multiplied by the factor K, assumed constant for each site, gives a cusec-time quantity which is readily convertible to foot-acres.

By equating the volume of the lake in foot-acres to this quantity the value of K is easily determined. In the diagram shown on plate XVI one square is equivalent to $8 \times 2000{,}000$ K cusec-hours or $8 \frac{\times 200{\cdot}000 \times 2}{24} \times$ K foot-acres.

In the case of Skardu, Attock and Kalabagh a correction was applied for the amount of water already in the river when the flood came down, but in the case of Sasir Brangsa and Khalsar the time of passing the flood was short and the initial discharge small and no correction was made.

At Skardu the discharge of the Indus was estimated by assuming $n = {\cdot}030$ and working out the initial discharge from the cross section, hydraulic mean radius and slope at Attock and Kalabagh the correction taken was the measured discharge of 237,000 cusecs.

A table is given below showing the quantities for the various sites, the calculations for each site are shown in detail in Appendix F., see also plate XVI:—

Table 3.

Serial No.	Sites.	Slope per thousand.	Area.	H.M.R.	K.	Discharge.	n.	Mean Velocity $R^{\frac{2}{3}} \times K$
1	2	3	4	5	6	7	8	9
1	Sasir Brangsa	8·2	133,400	54·67	0·82	1,574,120	0·1651	11·8
2	Khalsar	3·75	104,896	48·00	1·05	1,454,900	0·0872	13·87
3	Skardu	2·00	57,300	25·80	2·009	1,005,000	0·0332	17·54
4	Attock	0·89	51,875	58·50	0·815	637,020	0·0315	12·28
5	Kalabagh.	0·50	32,658	30·10	1·57	496,400	0·0212	15·20

These variations in "n" are remarkable from the range of values obtained, a certain variation was to be expected but these variations would indicate that turbulence has an effect vastly in excess of what was expected.

During this flood certain observations were taken at Attock and calculations made on the usual departmental lines to determine the maximum discharge. Owing to the sudden nature of the flood the observers were only able to obtain four surface velocities from floating logs. Then calculating from a previously observed cross section and applying a factor of 0·9 to reduce the observed velocities to mean velocities a discharge of 841,000 cusecs was calculated. Again working from an assumed value of Kutters "n" of ·025 and the previously observed cross section a discharge of 755,000 cusecs was calculated, against a maximum of 511,300 given by the formula.

If either of these values be accepted as the maximum then the run off at Attock would be vastly in excess of the volume of water contained in the lake. From this it can be seen that the co-efficients in general use for flood discharges are open to grave doubts. However, in the absence of any other formulæ it is necessary to see what constants are desirable to bring the calculated results more in accordance with the actual discharges.

Some light may be thrown on the question by the examination of the discharges at Attock. By this method of calculation a value of n= ·0315 is obtained, while a calculation of the discharge based on a cross section and slope of the river with a value of n=·043 gives a discharge of 5,10,917 which is very close to the discharge given by the logarithmic formula. The difference between these two values of "n" is not hard to explain, the increase is due to turbulence and as turbulence increases so the value of "n" rises to a maximum of ·043 while the value of ·0315 is an intermediate value between the maximum and the ordinary value of n=·020. This implies as might be expected that the co-efficient K is not a true constant for the whole range of the flood at any site but varies with the degree of turbulence. This indicates that the values tabulated for the various sites are not absolutely the maximum values, but some intermediate values. The value of ·0872 for Khalsar is vastly in excess of the value of ·030 obtained from a discharge at low water.

Nearly all the discharges of rivers and torrents in heavy flood depend on surface velocity observations and here again a check on the conventional co-efficient of 0·9 is afforded by the calculated discharge at Attock.

Taking the discharge given by the logarithmic formula as correct a mean velocity of 9·86 feet/second is deduced from the area of the cross section, against a mean velocity of logs observed as 18·02 feet/second and from this it appears that the co-efficient used in the discharge 0·9 should be 0·55. It must be carefully noted however that the velocity of logs is not a true surface velocity, far from it; however as long as the only practicable way of observing flood velocities is by timing objects floating past it would seem desirable to reduce the co-efficient.

Nearly all our observations of daily discharges in high rivers depend on surface velocities and it would appear imperative to carry out some investigations to ascertain more exactly the relation between surface velocities and mean velocities in turbulent motion. I do not consider the results given above to be sufficiently accurate to justify the adoption of these co-efficients without further enquiry, but I consider that no storage project should be entered into till some further information is available on these points.

APPENDIX A.

Skardu Gauge.

While at Leh a telegram was received from the Chief Engineer stating that the gauge at Skardu was reported to be damaged and instructing us to see what could be done to put this right. I consulted the Tehsildar, Leh, who had been transferred from Skardu only a few months previously, as well as the Wazir Wazirat, who has his winter headquarters at Skardu. Both these officers knew the gauge well and on their information I decided to send B. Abdul Rahim to carry out the necessary work.

When B. Abdul Rahim arrived at Skardu he found that the wooden portion of the gauge up to 25 feet had been washed away, and he marked out the gauge on the rock below this level down to 11 feet. He also arranged with the Kashmir State Public Works Department engineer to carry on this graduation downwards as the water fell.

A cross section of the river at Skardu gauge site was also taken and is shown in plate XV.

After completing this work B. Abdul Rahim reached Srinagar on September 29th.

APPENDIX B.

Flood Warnings.

As already mentioned the system for conveying warning of a flood in the Shyok due to a burst of the Chong Kumdun dam depended on a gauge reader at Khalsar and three pairs of dak runners, one of each pair had always to be present at his post. To avoid any delay in conveying the warnings horses were to be provided for the dak runners in the event of a burst.

To get the system into working order the gauge reader at Khalsar sent off postcards with gauge readings to the Executive Engineer, Discharge Division, by one of the runners, while the other had to remain at his post. It was arranged that in the event of a flood the gauge reader should send a special letter to the Wazir Wazirat, Leh, stating at what time the flood began to rise, the height reached on the gauge and the time during which the water remained at this highest reading.

The necessary authority was issued for the Wazir Wazirat to send "clear the line" telegrams to the Punjab Government regarding any flood.

The system worked satisfactorily when the flood came at 8 A. M. on the 16th; information reached Leh in twelve hours, the messengers having started from a height of 10,000 feet, crossed a pass 17,600 feet high and dropped down to 11,500 feet at Leh in a distance of 37 miles, and the warning wire from Leh was delivered in Simla at 6-15 A. M. on the 17th.

While the warning system worked satisfactorily this year the danger of relying solely on these measures to communicate with Leh lies in the fact that the Khardung pass is frequently closed for two or three days at a time due to storms even during the height of summer. It is even more undesirable to employ a system of bonfires or other visual signals over the pass as quite frequently clouds gather on it for days on end though there may be no heavy precipitation.

I therefore strongly recommend that a duplicate warning be arranged for from Skardu. The flood reached Skardu very few hours after this year's warning reached Leh and the two wires should arrive at almost the same time.

I recommend that the following works should be undertaken as soon as possible next year so as to facilitate the prediction of the amount of water in the lake and also to give some idea of the size of any future flood.

At the lake itself I recommend a series of cairns suitably marked be erected at each fifty and hundred foot contour level working from the bench mark fixed by the party this year. These should so far as possible be erected along some even slopes in straight lines and a section of the ground supplied to the Punjab Government so that it may be possible for any one in future to report that the water level was so many paces from a certain cairn, on receipt of this information the water level could be derived from the section. This would enable the volume of water to be estimated from the curve in plate X.

At Khalsar the rock is rough and I do not anticipate that after a few years the marks made this year will remain visible. I therefore recommend that the gauge at Khalsar be properly dressed in a smooth strip, graduated by feet and quarter feet from as far as possible below this year's zero up to a 10 foot reading, after this only feet need be graduated up to a level about five feet above this year's flood level.

These works could be readily done by the Kashmir State Public Works Department who have an overseer at Leh.

Then in any year in which it is reported that the dam exists a gauge reader and dak runners should be engaged to work between Khalsar and Leh, and a man despatched to the lake as soon as the Sasir pass is open to report the water level in the lake and the state of the glacier.

I do not consider it necessary to wait for any information about the duration of the flood peak in future as even the maximum gauge reading cannot be relied on for a prediction and the height of the flood peak at Attock is determined from the volume in the lake. The orders for the gauge reader would be to report the time at which the gauge began to rise and the height to which it rose.

At the same time I recommend that the Skardu gauge be read and reported regularly in future.

The necessary authority should be arranged for the Wazir Wazirat and Tehsildar Skardu to send "clear the line" messages to the Punjab Government about any flood. The duplicate warning is necessary as the Khardung pass may be blocked, or the telegraph line to Skardu may be out of order as was the case this year.

APPENDIX C.

1929 Flood Rises.

Sasir Brangsa.

The dam broke in the early hours of the 15th August, and the flood reached Sasir Brangsa, 10 miles below the dam, at about 6 A. M., it rose 85 feet in four hours to about 10 A. M., and remained at this level till about 11 A. M. After this the water gradually subsided and fell 52 feet in six hours to a level 33 feet above the morning gauge by 5 P. M. After this the fall was very slow and in 24 hours the fall was nine feet, that is according to the statement of the man in charge of the ford, and on the 16th at 5 P. M. the water was still 24 feet above its initial level, while on the 17th morning the level was little above normal.

Khalsar.

The flood reached Khalsar about 8 A. M. on the 16th August, and rose 45 feet from a gauge of 8 feet to 53 feet in about half hour, it remained at this level up to 10 A. M. and then rose suddenly 18 feet to a gauge of 71 feet at which level it remained till 3 P. M. giving a total rise of 63 feet. After this it dropped 50 feet in an hour to a gauge of 21 feet and continued to fall and by the 17th morning the water was 9½ feet below its original level on the 16th.

I am of the opinion that the sudden rise at 10 A. M. and fall at 3 P. M. of the gauge was due to movement of a large shingle bar.

Skardu.

The flood reached Skardu at 8-30 P. M. on the 16th, the gauge being 17 feet at 6 P.M. By 9 P. M. the gauge had risen 8 feet in half an hour to a gauge of 25 feet, it reached its peak of 42 feet at midnight having risen 17 feet in 3 hours. The water remained at this level up to 3 A. M. on 17th, after which it dropped 7 feet in 4 hours and stood at a gauge of 35 feet at 7 A. M. The gauge was carried away but the fall continued, and it is estimated that the gauge was about 19 feet at 7 P. M. on the 17th.

Bunji.

According to information received from the Resident in Kashmir the flood reached Bunji at 5 A. M. on 17th August and rose (presumably from 7 feet) to 31 feet at 8-10 A. M. and reached its peak of 44 feet at 1-45 P. M. At 7-50 P. M. it subsided from 44 feet to 34 feet and early in the morning of 18th August it fell to 19 feet finally falling to 7 feet at mid-day.

Attock.

On the evening of 17th August the Attock gauge was 27·5 feet, the flood arrived at 2-15 A. M. on 18th August and rose 16·5 feet to a 44 feet gauge by 8 A. M., by 11 A. M. it had risen a further 6 feet to a gauge of 50 feet and by 2 P. M. it had risen a further 4·5 feet to a gauge of 54·5 feet. The peak of 56 feet was reached at 6 P. M. giving a total rise of 28·5 feet in about 16 hours The gauge remained steady at the peak for about 2½ hours and then began to fall, reaching a gauge of 50 feet at 6 A. M. on 19th August. It fell 4½ feet by 11-30 A. M. and by 5-30 P. M. had fallen to 40 feet. The fall then became more gradual and the gauge of 28 feet was reached at 8 A. M. on 21st August.

APPENDIX D.

Flood Levels at Attock.

The observations of flood levels taken this year showing the Shyok flood on the 18th August as well as the flood on the 28th August are shown in plates XVIII to XXI, while an index plan showing the position of the cross sections is shown on plate XVII.

The levels of the flood of 1841 are also shown on the plates for purposes of comparison. Taking into consideration that the volume impounded by the dam this year was very nearly the maximum ever held up it is obvious that the menace from the Shyok is not so great as had been anticipated.

A certain amount of heading up occurred at Attock due to the Shyok flood, but this was not of long enough duration to affect the Kabul river very far up, while the rain flood had a very much greater effect.

It can be clearly seen that no rain flood could produce levels equal to the flood of 1841.

The flood in 1841 was due to a block at the Hatu Pir spur of Nanga Parbit. A portion of the hillside fell into the river bed and completely blocked the Indus for about six months. When this dam broke a tremendous volume of water was let loose. It is only from some similar catestrophe that the levels of 1841 could again be reached.

APPENDIX E.

Calculation of Hydraulic Constants.

Sasir Brangsa.

The table below shows the various quantities got from the cross section and the product $AR^{\frac{2}{3}}$ for Sasir Brangsa.

	Area.	W. P.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
Stage 1 ..	133,400	2,440	54·67	14·4	1,920,960	8·2 or S=·0082
,, 2 ..	26,220	1,270	20·65	7·52	197,174	
,, 3 ..	16,460	980	16·79	6·55	107,813	

The quantity $AR^{\frac{2}{3}}$ is plotted on a time basis. Taking 8 hours per inch and 200,000 per inch as the unit for $AR^{\frac{2}{3}}$.

The area of this figure comes to be 10 sq. ins. Then area in sq. ins. $\times 2 \times K \times \frac{8}{24} \times 2$ = lakhs of foot-acres in lake.

$$\frac{10 \times 4}{3} K = \text{Volume of lake in lakhs of foot-acres,}$$

$$= 10{\cdot}95$$

$$\therefore K = 0{\cdot}82$$

$$\text{and } 0{\cdot}82 = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$$

$$= \frac{1{\cdot}486}{n} \times {\cdot}0082^{\frac{1}{2}}$$

$$n = 0{\cdot}1651$$

and mean velocity $= R^{\frac{2}{3}} \times K = 14{\cdot}4 \times 82 = 11{\cdot}8$ ft./sec.

and peak discharge $= A \times V = 133{,}400 \times 11{\cdot}8$

$= 1{,}574{,}100$ cusecs.

Khalsar.

Calculations of Shyok Flood Discharge at Khalsar.

	Area.	W.P.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
Stage 1 ..	86,022	2,167	39·69	11·63	100,436	3·75 or S=·0038
„ 2 ..	104,896	2,185	48·00	13·21	1,385,676	
„ 3 ..	32,575	1,724	18·89	7·09	230,957	
„ 4 ..	..	..	..	..	11,604	

Area of $(A \times R^{\frac{2}{3}}) \times 2K \times \frac{8}{24} \times 2$ = foot acres in lake

Area by diagram = 7·80 sq. ins.

$\therefore 7{\cdot}8 \times \frac{4}{3} K = 10{\cdot}95$

or $K = 1{\cdot}05$

and as $K = \frac{1{\cdot}486}{n} \times S^{\frac{2}{3}}$

$\therefore \quad 1{\cdot}05 = \frac{1{\cdot}486}{n} \times {\cdot}0038^{\frac{1}{2}}$

$\therefore \quad n = 0{\cdot}0872$

and mean velocity $= R^{\frac{2}{3}} \times K = 13{\cdot}21 \times 1{\cdot}05 = 13{\cdot}87$ ft./sec.

$\therefore$ Discharge $= A \times V = 104{,}896 \times 13{\cdot}87$

$= 1{,}454{,}900$ cusecs.

In the original drawing from which these calculations were made the scales used for Skardu, Attock and Kalabagh were 1″ = 8 hours and 100,000 = 1″ for the $AR^{\frac{2}{3}}$ scale, but they were replotted to the same scales as Khalsar and Sasir Brangsa on plate XVI for purposes of comparison.

Skardu.

In the cases of Skardu due allowance must be made for the water already in the river.

To estimate this calculations for stage 4, *i. e.*, a gauge of 17 ft. were worked out assuming a value of n=0·030,

$$Q = AV = A \times \frac{1{\cdot}49}{n} \times S^{\frac{1}{2}} R^{\frac{2}{3}}$$

$= 14{,}670 \times 11{\cdot}30$

$= 165{,}771$ cusecs.

As the period of passing of the flood was 48 hours the volume passed by the normal river supply is 165,800×4 foot acres = 6·63 lakhs of foot acres.

The quantities in the table below were then plotted on a time base.

	Area.	W.P.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.	Remarks.
Stage 1 ..	26,110	1,605	16·27	6·42	167,626	2 0	
,, 2 ..	57,300	2,220	25·81	8·73	500,229	or S= ·0020	
,, 3 ..	43,710	2,370	18·44	6·98	305,096		
,, 4 .. with gauge 17 ft.	14,670	1,288	11·4	5·07	74,377	..	Flowing at normal conditions

Then K × area or curve × $\frac{2}{3}$ = Volume in lake,
+ volume in river for 2 days.

or $13{\cdot}2 \times \frac{2}{3} \times K = 10{\cdot}95 + 6{\cdot}63$

i. e. $K = 2{\cdot}009$

since $K = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$

$2{\cdot}009 = \frac{1{\cdot}486}{n} \times {\cdot}0020^{\frac{1}{2}}$

$n = 0{\cdot}0332$

and mean velocity $= R^{\frac{2}{3}} \times K = 17{\cdot}54$ ft./sec.

and discharge $= AV = 57{,}300 \times 17{\cdot}54$

$= 1{,}005{,}040$ cusecs.

Attock.

In the same way, for Attock, assuming that the water in the river is 237,000 as measured at Kalabagh and plotting the curve from the observations in the table below the following results are obtained:—

Area.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
51,875 ..	58·5	15·07	781,756	0·29
49,437 ..	56·5	14·72	727,713	
45,369 ..	52·5	14·02	636,073	or S= ·0003
41,283 ..	49·1	13·41	553,605	
33,376 ..	41·0	11·89	396,841	

Area of curve $\times K \times \frac{8}{24} \times 2 =$ Volume in lake + volume in river.

$$\text{or } 38{\cdot}32 \times \tfrac{2}{3} \times K = 10{\cdot}95 + \tfrac{50}{24} \times 2 \times 2{\cdot}37$$

$$\text{or } K = 0{\cdot}815$$

$$\text{and } K = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$$

$$\text{or } n = \frac{1{\cdot}486}{0{\cdot}815} \times {\cdot}0003^{\frac{1}{2}}$$

$$= 0{\cdot}0315$$

$$\text{and mean velocity} = R^{\frac{2}{3}} \times K = 15{\cdot}07 \times {\cdot}815 = 12{\cdot}28 \text{ ft./sec.}$$

$$\text{Discharge} = A \times V\ 51{,}875 \times 12{\cdot}28$$

$$= 637{,}020 \text{ cusecs.}$$

Kalabagh.

For Kalabagh making the same assumption as before regarding the water in the river, the area of the curve plotted from the data below is 2·14 sq. ins.

Area.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
29,737 ..	28·61	9·35	278,041	0·5
30,867 ..	29·40	9·53	294,163	or S = ·0005
31,819 ..	29·87	9·63	307,517	
32,658 ..	30·10	9·68	316,129	

Area $\times K^{\frac{2}{3}}$ = volume in lake + volume in river.

$$21{\cdot}4 \times \tfrac{2}{3} \times K = 10{\cdot}95 + \tfrac{58}{24} \times 2 \times 2{\cdot}37$$

$$K = 1{\cdot}57$$

$$\text{and } K = \frac{1{\cdot}486}{n} \times {\cdot}0005^{\frac{1}{2}}$$

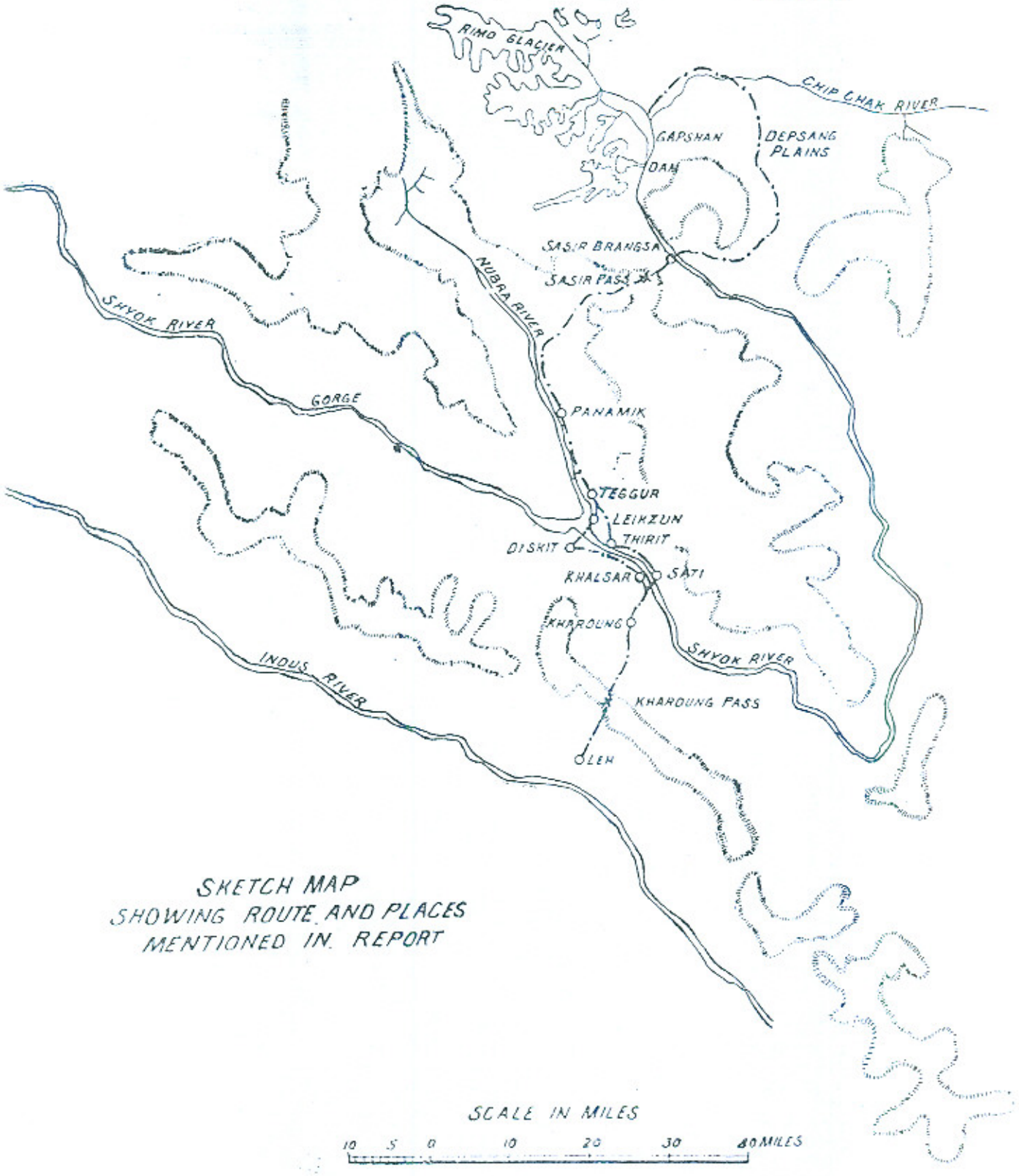
$$\text{or } n = \frac{1{\cdot}486}{1{\cdot}57} \times {\cdot}0005^{\frac{1}{2}} = 0{\cdot}212$$

$$\text{and mean velocity} = R \times K = 9{\cdot}68 \times 1{\cdot}57 = 15{\cdot}20 \text{ ft./sec.}$$

$$\text{and discharge} = A \times V = 32{,}658 \times 15{\cdot}20$$

$$= 496{,}400 \text{ cusecs.}$$

PLATE I



SKETCH MAP
SHOWING ROUTE AND PLACES
MENTIONED IN REPORT

SCALE IN MILES

10 5 0 10 20 30 40 MILES

LONGITUDINAL SECTION OF SHYOK RIVER
ABOVE SASIR BRANGSA

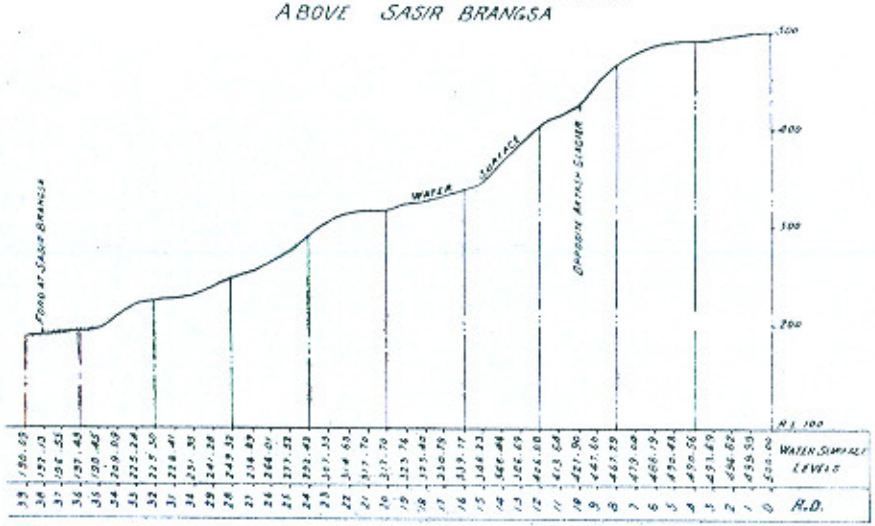


PLATE II.

LONGITUDINAL SECTION OF SHYOK RIVER
FROM SATI TO DISKIT

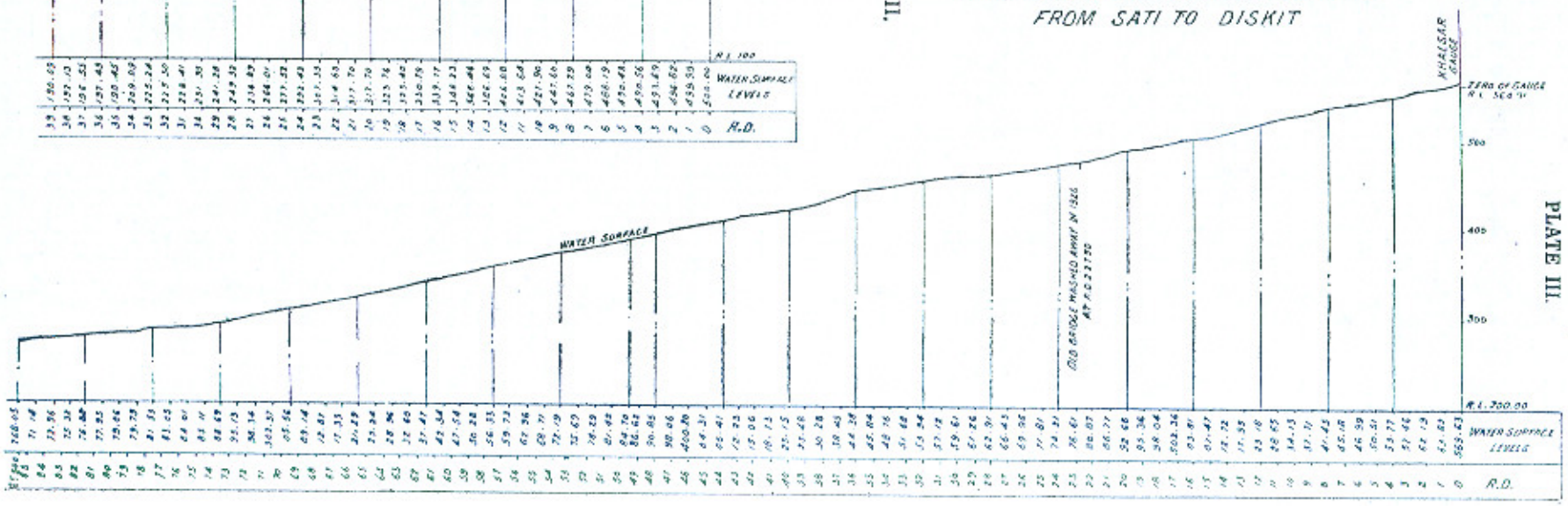


PLATE III.

PLATE IV.

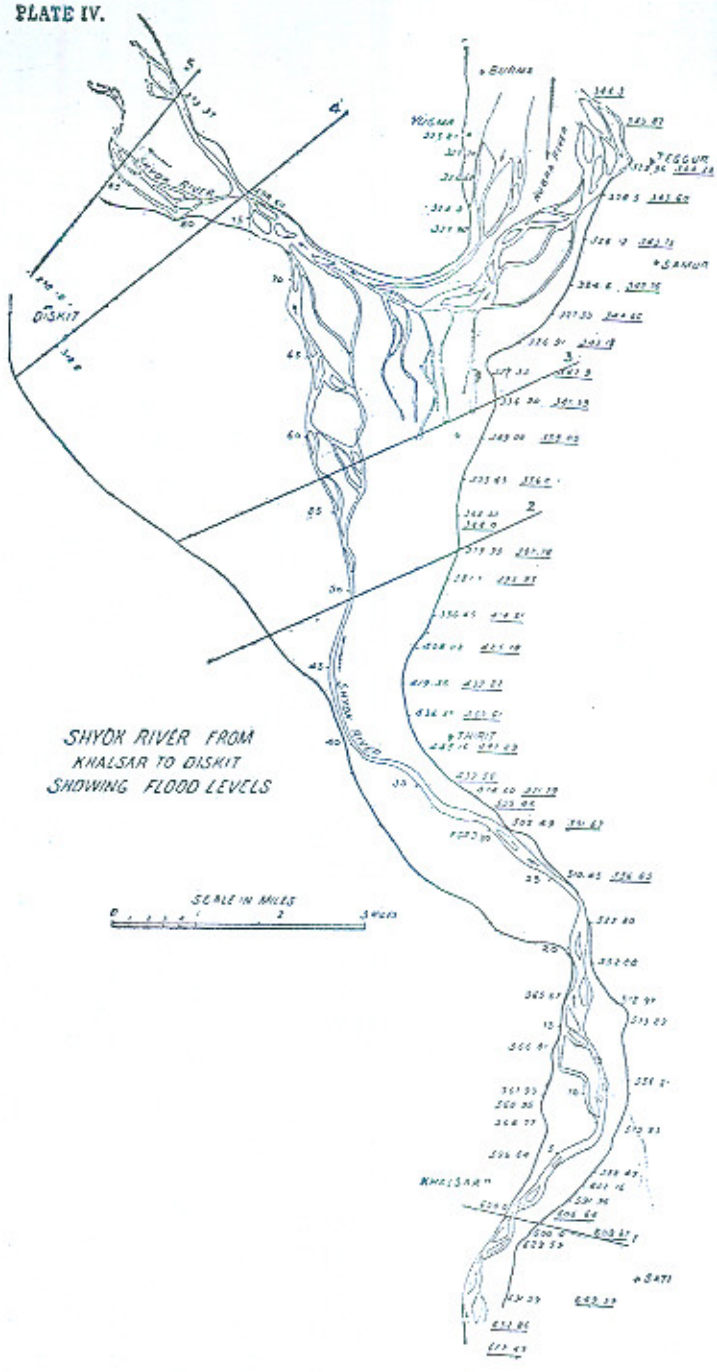

SHYOK RIVER FROM
KHALSAR TO DISKIT
SHOWING FLOOD LEVELS
SCALE IN MILES
DISKIT
KHALSAR
TEGGUR
SAMUR
SATTI
TH-RIT

PLATE V.

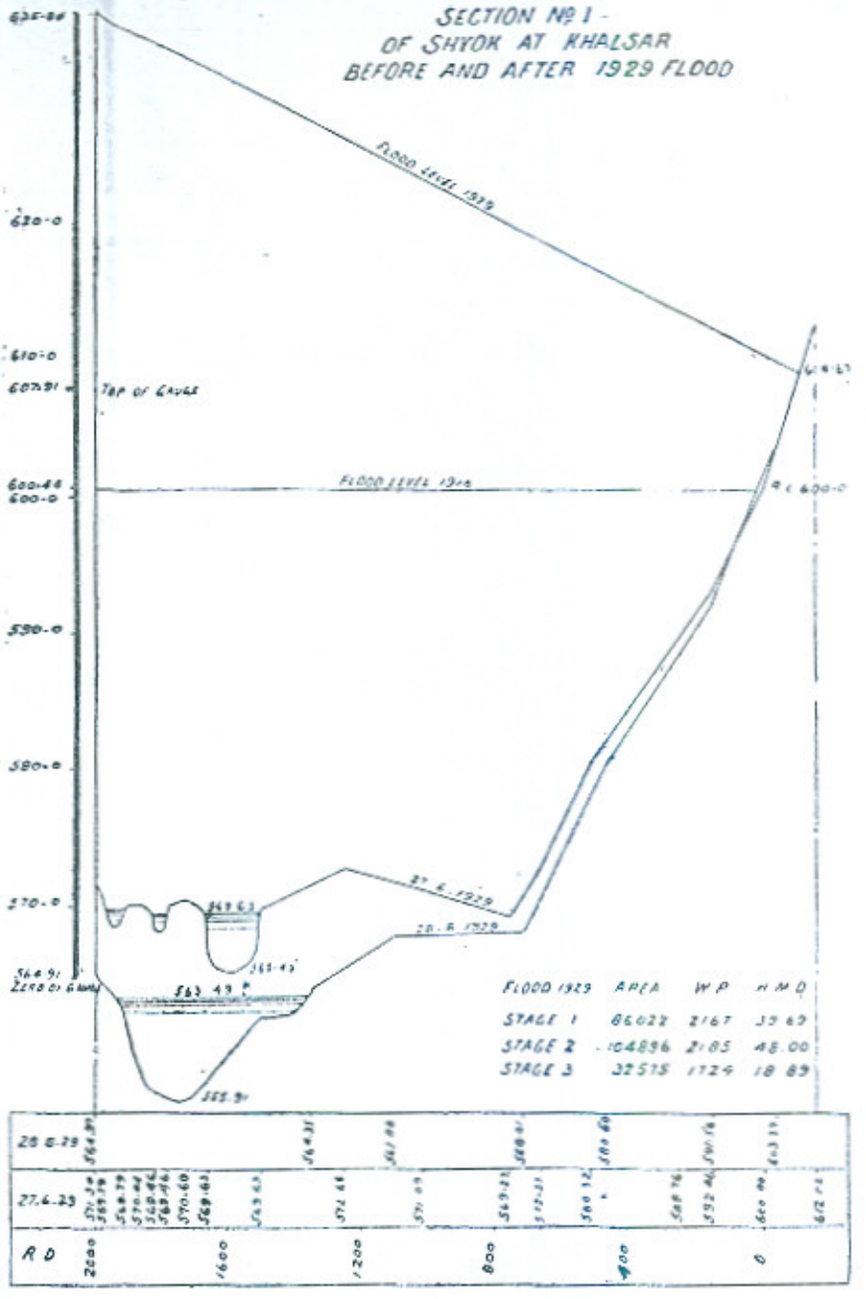
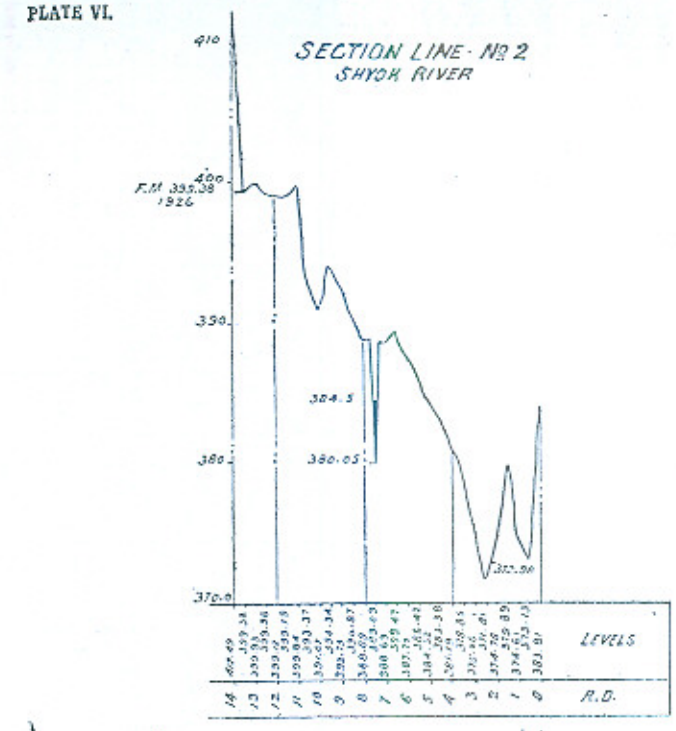

SECTION No 1 -
OF SHYOK AT KHALSAR
BEFORE AND AFTER 1929 FLOOD
FLOOD LEVEL 1929
TOP OF GAUGE
FLOOD LEVEL 1926
630·0
610·0
600·0
590·0
580·0
570·0
Zero of Gauge
563·49
565·91
27·6·1929
28·6·1929
FLOOD 1929 AREA W.P. H.M.D.
STAGE 1 86022 2167 39·69
STAGE 2 104896 2185 48·00
STAGE 3 32515 1724 18·89
28·6·29
27·6·29
R D
2000
1600
1200
800
400
0

PLATE VI.


SECTION LINE - No 2
SHYOK RIVER
410
400
390
380
370
F.M. 395.38
1926
384.5
380.05
382.00
LEVELS
R.D.

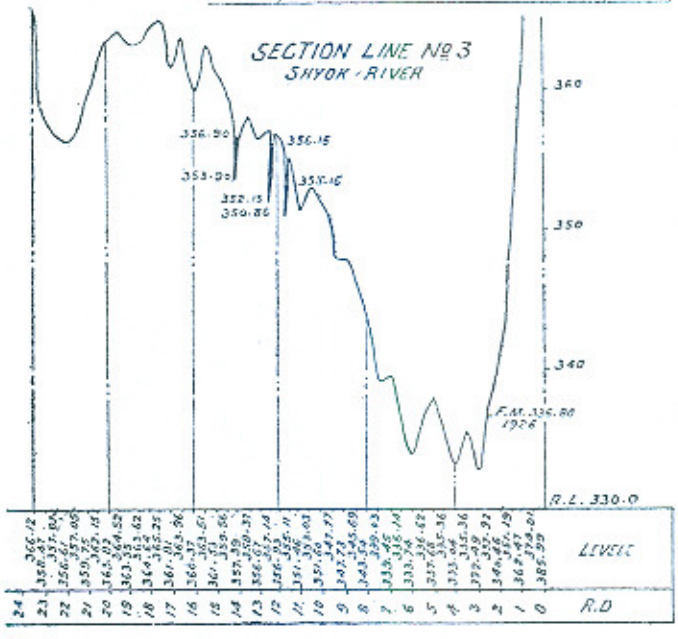
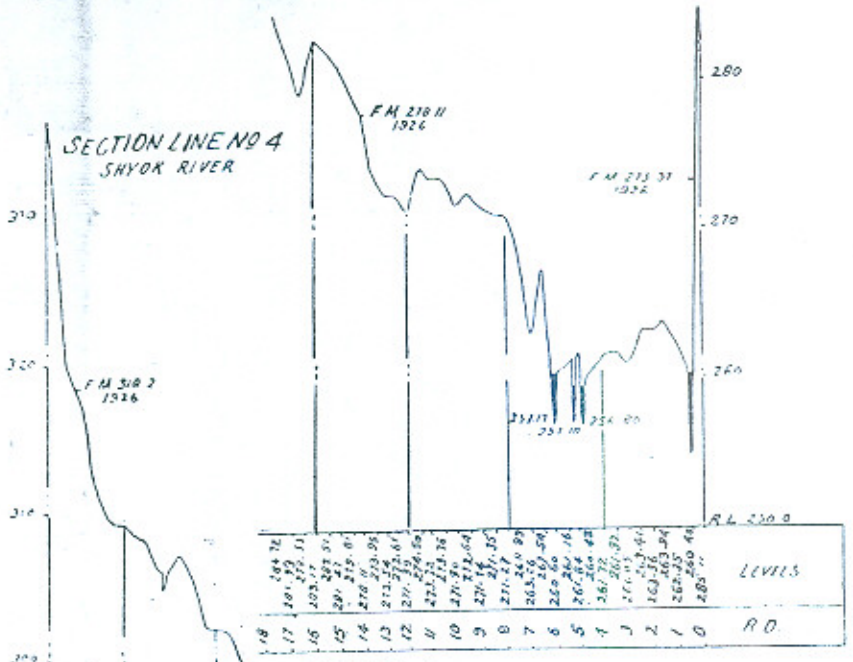

SECTION LINE No 3
SHYOK - RIVER
360
350
340
356.90
356.15
353.00
351.16
352.15
350.80
F.M. 336.88
1926
R.L. 330.0
LEVELS
R.D

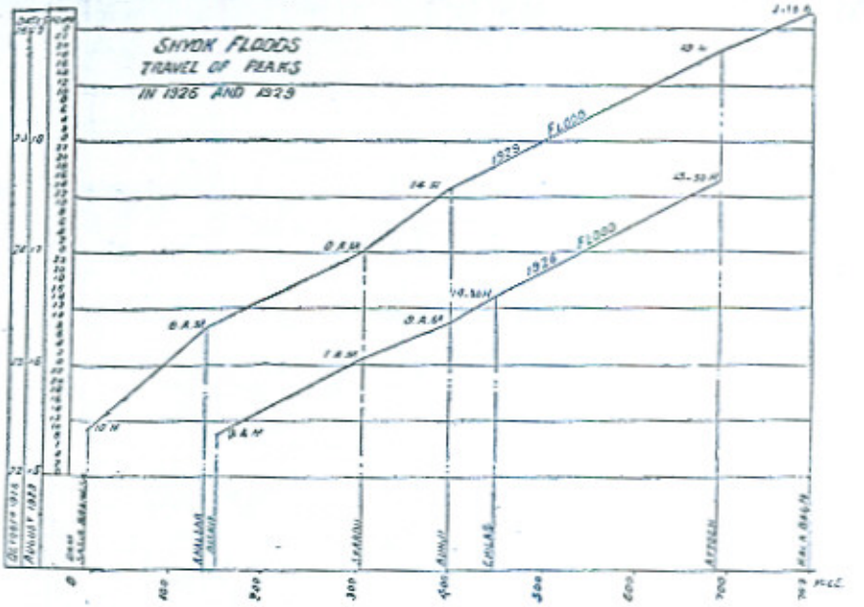
PLATE VII.

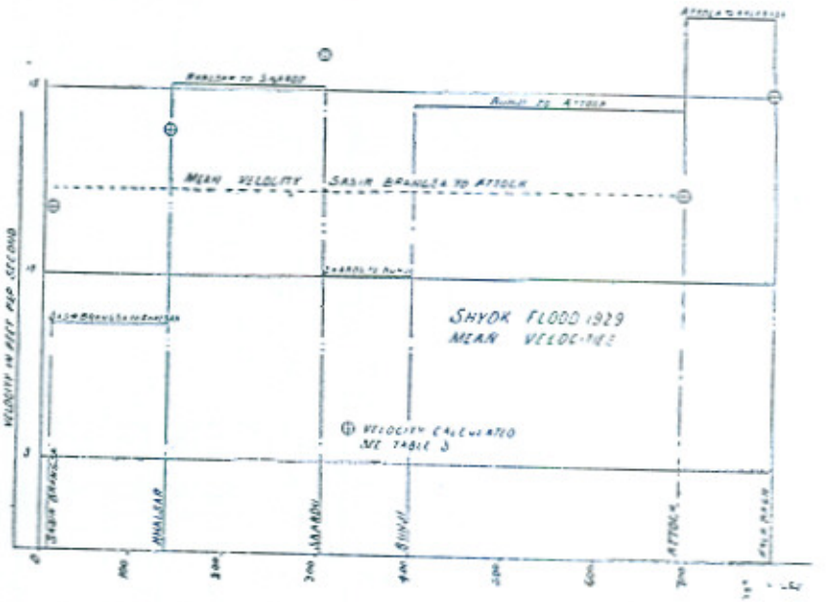
SECTION LINE No 5
SHYOK RIVER



SECTION LINE No 4
SHYOK RIVER

PLATE VIII


SHYOK FLOODS
TRAVEL OF PEAKS
IN 1926 AND 1929
1929 FLOOD
1926 FLOOD


MEAN VELOCITY
SHYOK FLOOD 1929
MEAN VELOCITIES

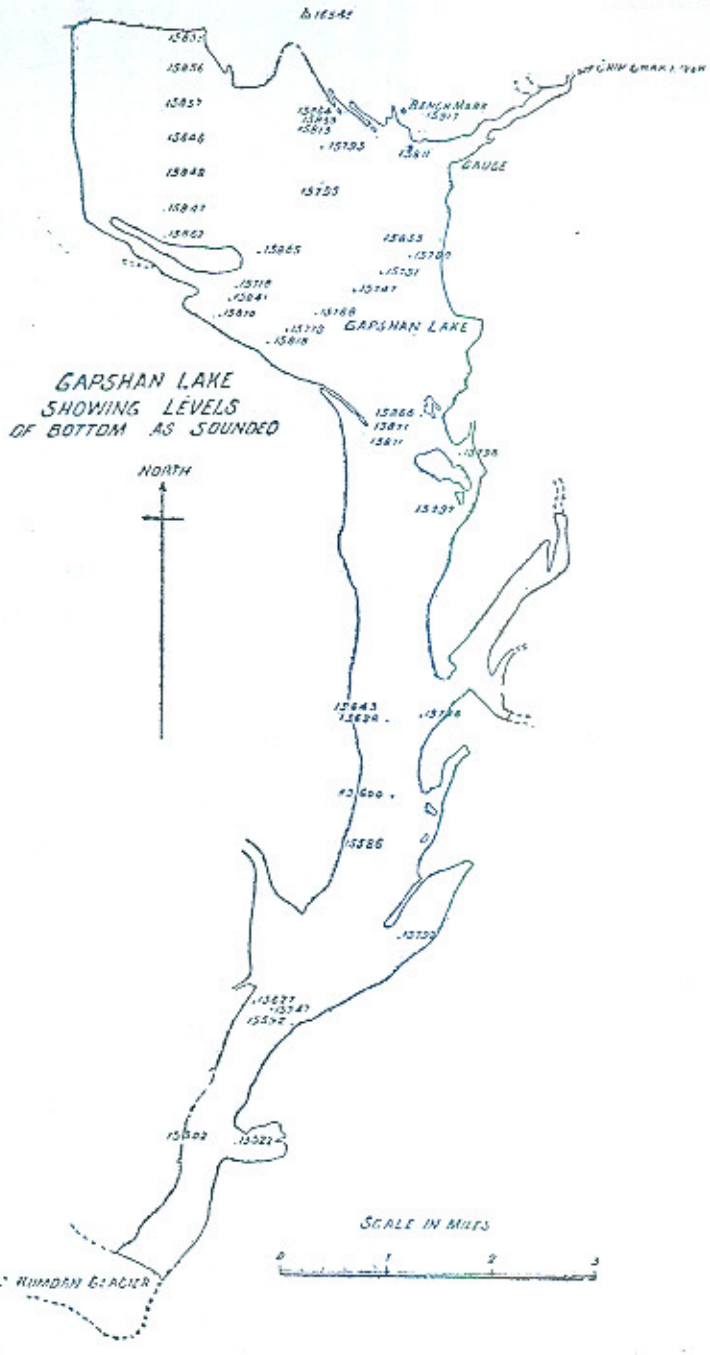
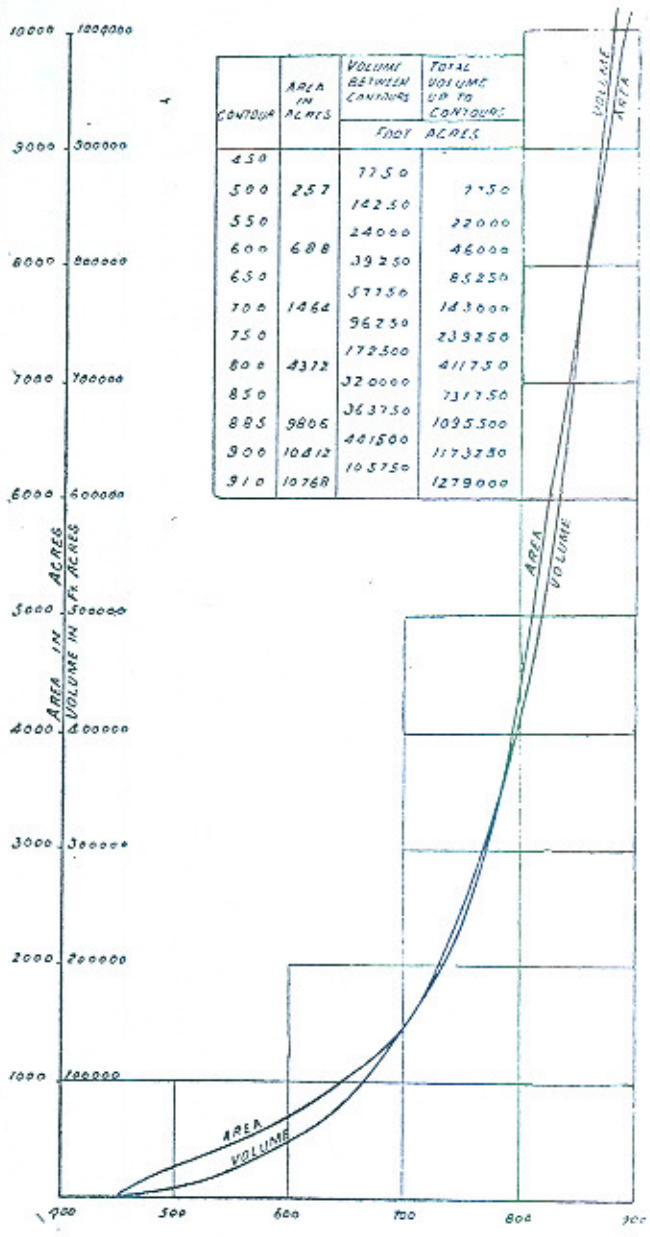

GAPSHAN LAKE
SHOWING LEVELS
OF BOTTOM AS SOUNDED
NORTH
GAPSHAN LAKE
GAUGE
BENCH MARK
SCALE IN MILES
0
1
2
3
CHOIL RHADAN GLACIER

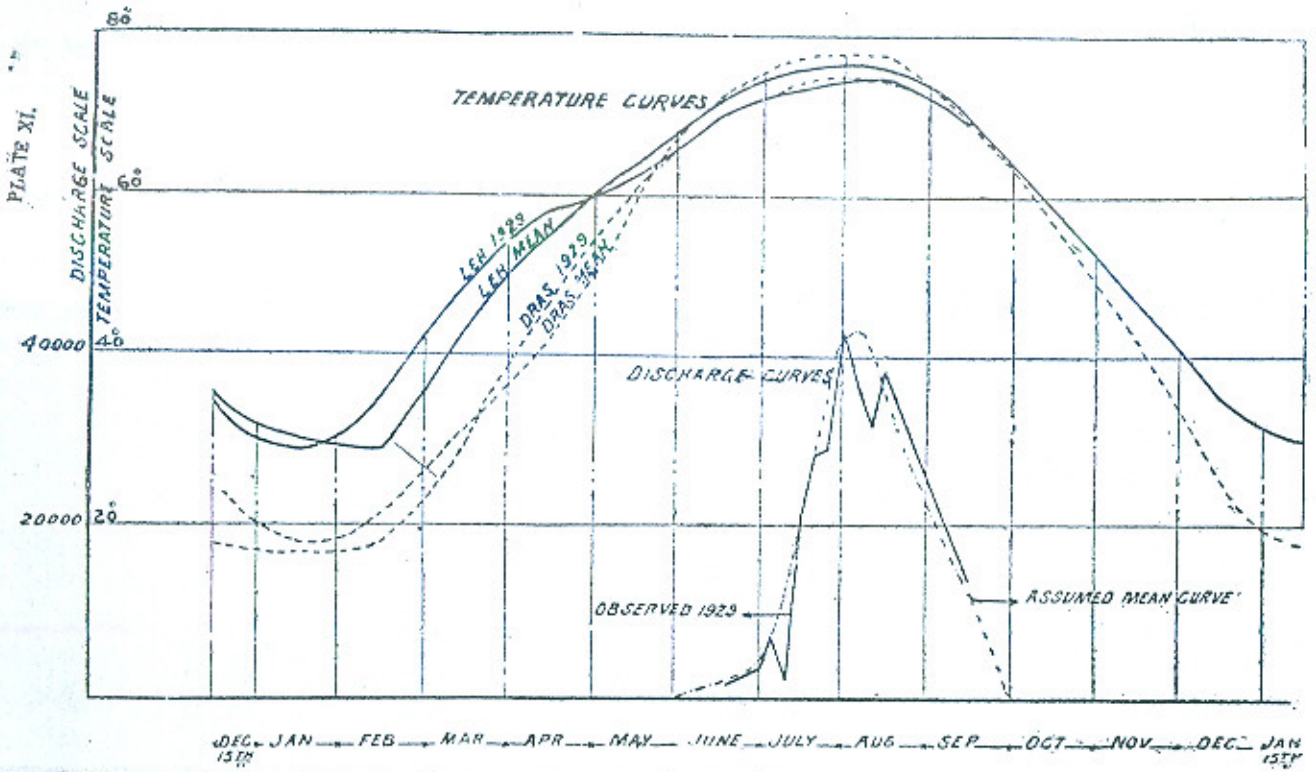
PLATE X.

GAPSHAN LAKE
AREAS AND VOLUMES



CONTOUR	AREA IN ACRES	VOLUME BETWEEN CONTOURS	TOTAL VOLUME UP TO CONTOURS
		FOOT ACRES	
450		7750	
500	257	142.50	7750
550		240.00	22000
600	688	392.50	46000
650		577.50	85250
700	1464	962.50	143000
750		1725.00	239250
800	4372	3200.00	411750
850		3637.50	731750
885	9806	4615.00	1095500
900	10812	1057.50	1173250
910	10768		1279000

PLATE XI.



TEMPERATURES AT LEH AND DRAS
DISCHARGE AT KHALSAR

PLATE XII.

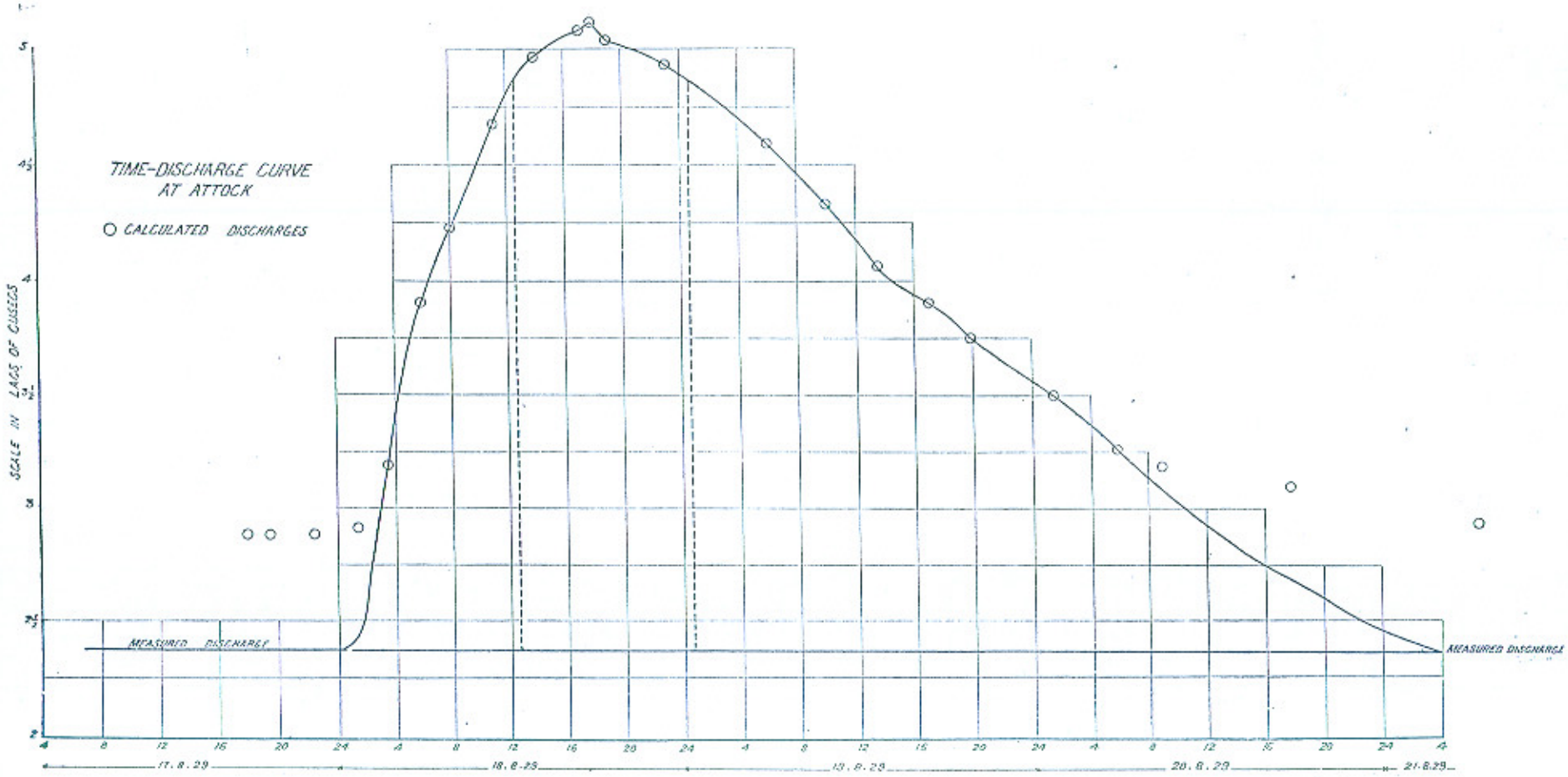

TIME-DISCHARGE CURVE AT ATTOCK
○ CALCULATED DISCHARGES
SCALE IN LACS OF CUSECS
MEASURED DISCHARGE
MEASURED DISCHARGE
17.8.29
18.8.29
19.8.29
20.8.29
21.8.29

PLATE XIII.

CURVE FOR PREDICTION OF MAX: RISE AT ATTOCK FROM GAPSHAN LAKE LEVELS

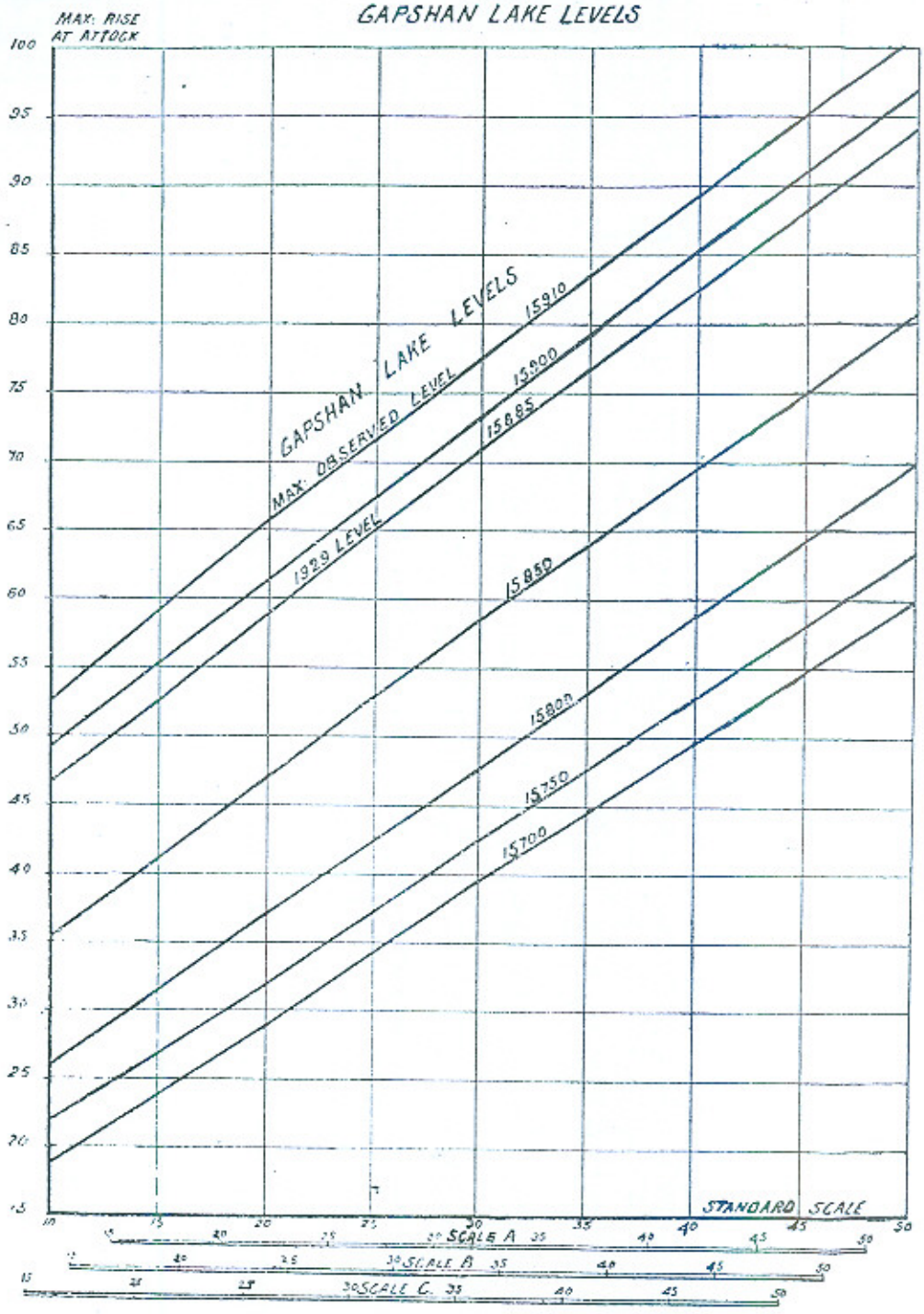
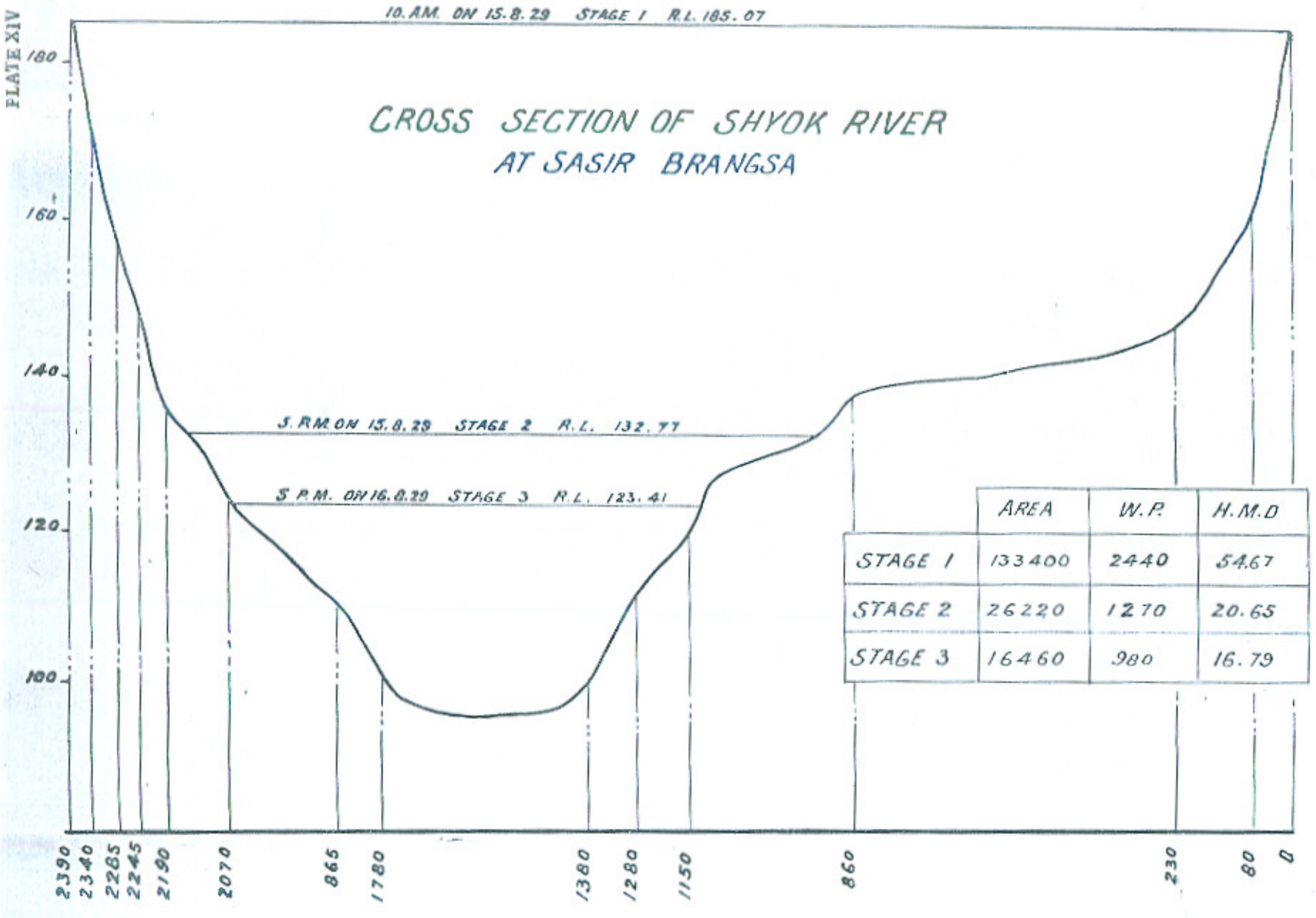
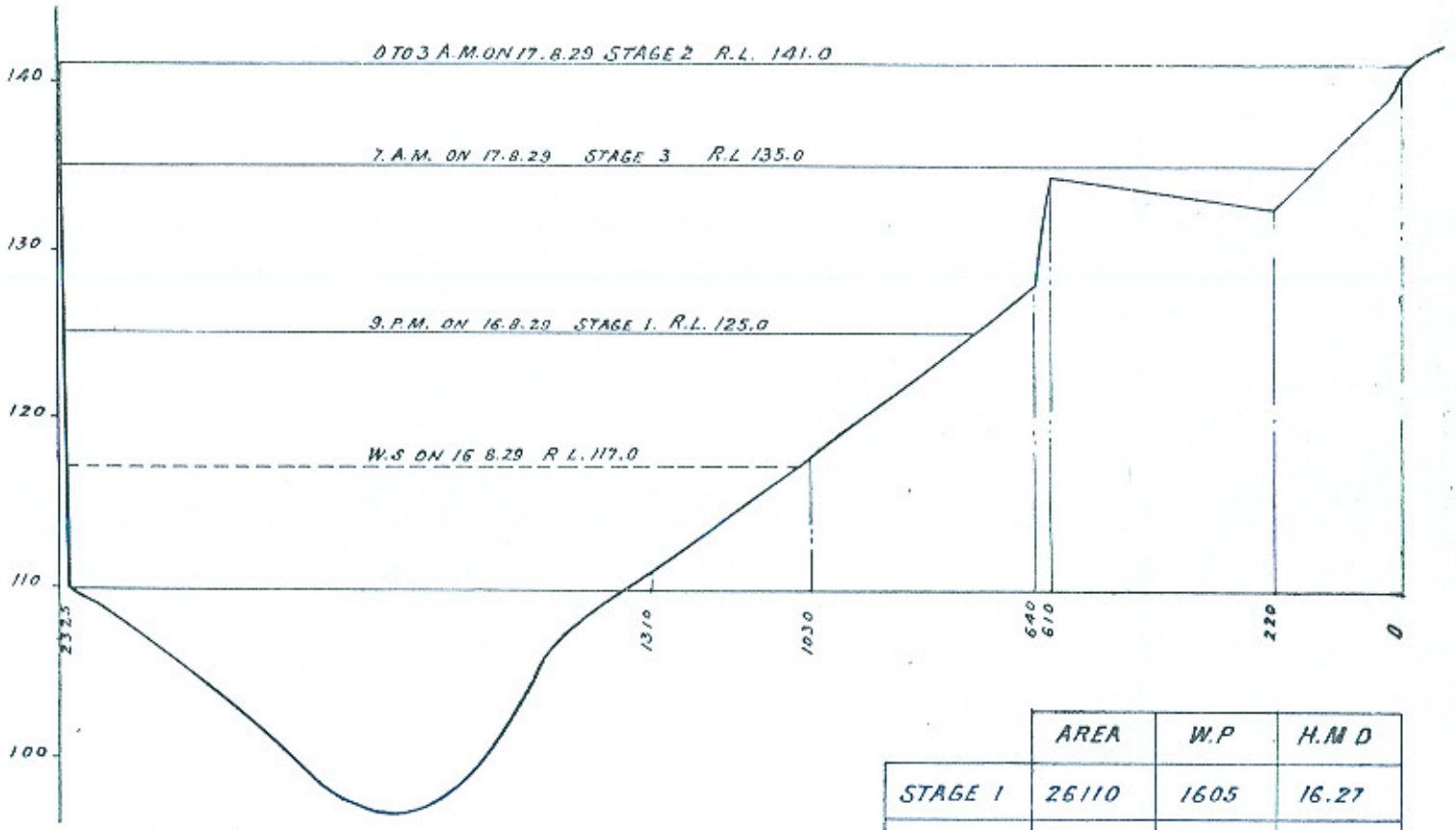


PLATE XIV



	AREA	W.P.	H.M.D
STAGE 1	133400	2440	54.67
STAGE 2	26220	1270	20.65
STAGE 3	16460	980	16.79

PLATE XV.



CROSS SECTION OF INDUS AT SKARDU

	AREA	W.P	H.M D
STAGE 1	26110	1605	16.27
STAGE 2	57300	2220	25.81
STAGE 3	43710	2370	18.44
STAGE 4 WITH GAUGE 17	14670	1288	11.40

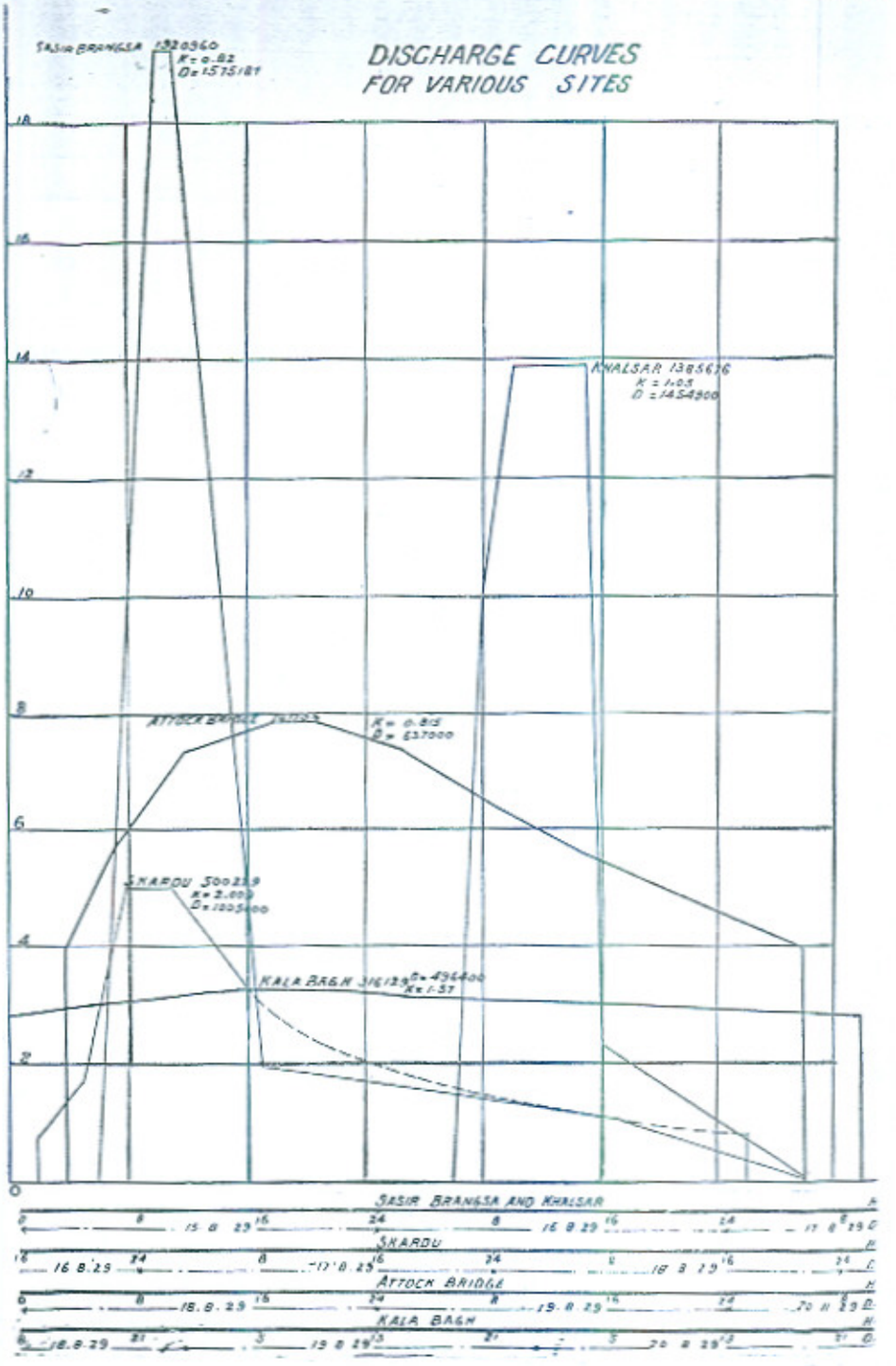
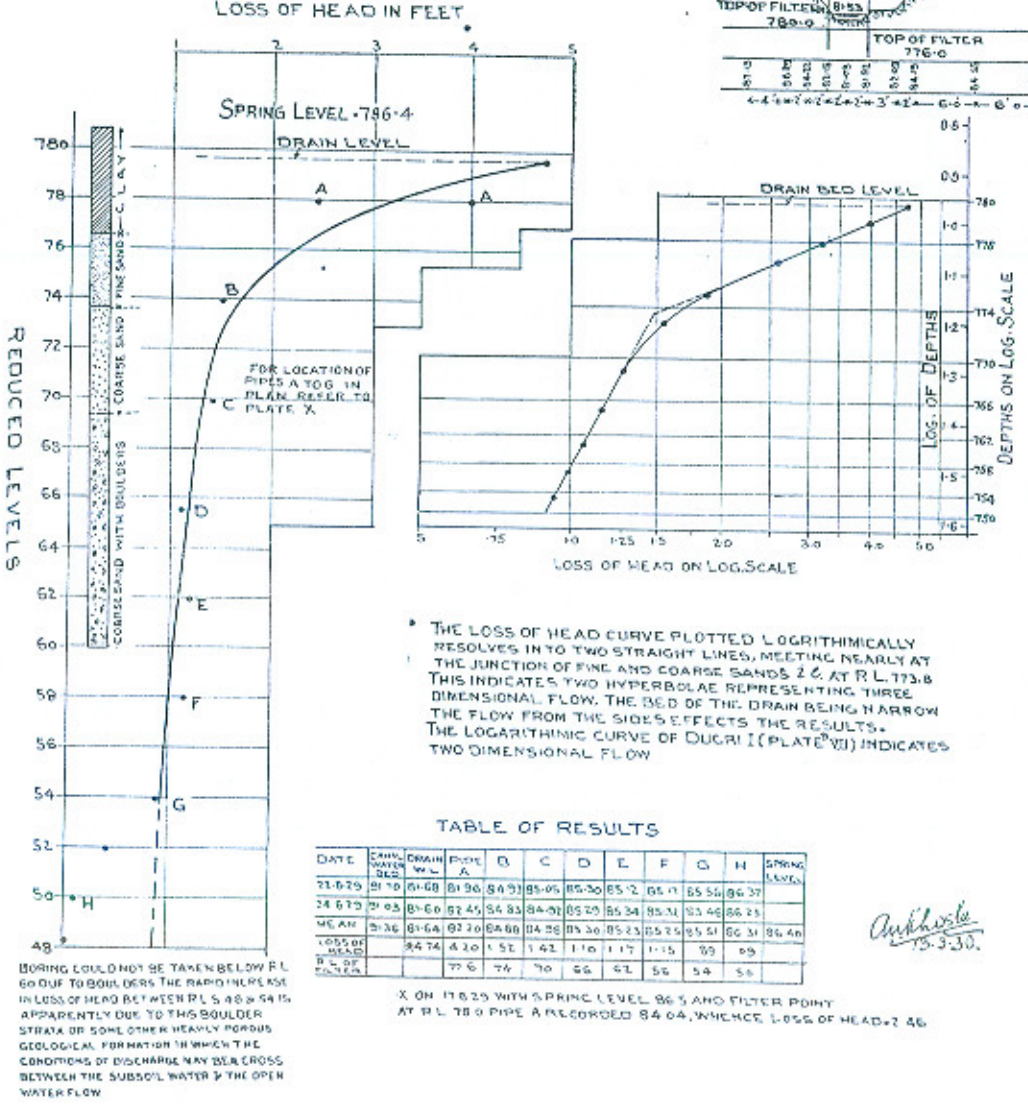

DISCHARGE CURVES
FOR VARIOUS SITES
SASIR BRANGSA 1320960
K = 0.82
D = 1575181
KHALSAR 1385626
K = 1.05
D = 1454900
ATTOCK BRIDGE
K = 0.85
D = 837000
SKARDU 500239
K = 2.00
D = 1005000
KALA BAGH 316139
D = 494400
K = 1.37
SASIR BRANGSA AND KHALSAR
SKARDU
ATTOCK BRIDGE
KALA BAGH

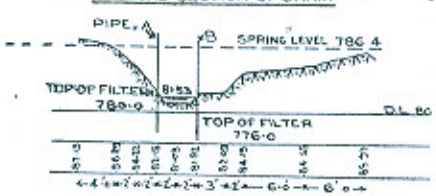
PLATE A

LOSS OF HEAD CURVE

JAURIAN SYPHON



TYPICAL SECTION OF DRAIN



THE LOSS OF HEAD CURVE PLOTTED LOGRITHIMICALLY RESOLVES IN TO TWO STRAIGHT LINES, MEETING NEARLY AT THE JUNCTION OF FINE AND COARSE SANDS 2 & AT R.L. 773·8 THIS INDICATES TWO HYPERBOLAE REPRESENTING THREE DIMENSIONAL FLOW. THE BED OF THE DRAIN BEING NARROW THE FLOW FROM THE SIDES EFFECTS THE RESULTS. THE LOGARITHMIC CURVE OF DUCRI I (PLATE VII) INDICATES TWO DIMENSIONAL FLOW

TABLE OF RESULTS

DATE	CANAL WATER LEVEL	DRAIN W.L.	PIPE A	B	C	D	E	F	G	H	SPRING LEVEL
23-8-29	81·10	81·68	81·96	84·91	85·05	85·30	85·12	85·11	85·54	86·37	
24-8-29	81·05	81·60	82·45	84·83	84·91	85·25	85·34	85·31	85·46	86·23	
MEAN	81·36	81·64	82·20	84·86	84·98	85·26	85·23	85·23	85·51	86·31	86·46
LOSS OF HEAD			84·74	4·20	1·52	1·42	1·16	1·17	1·15	·89	·89
R.L. OF FILTER				77·6	74	70	66	62	56	54	56

BORING COULD NOT BE TAKEN BELOW R.L. 60 OWING TO BOULDERS THE RAPID INCREASE IN LOSS OF HEAD BETWEEN R.L. 54·8 & 54·15 APPARENTLY DUE TO THIS BOULDER STRATA OR SOME OTHER HEAVILY POROUS GEOLOGICAL FORMATION IN WHICH THE CONDITIONS OF DISCHARGE MAY BE CROSS BETWEEN THE SUBSOIL WATER & THE OPEN WATER FLOW

X ON 17.8.29 WITH SPRING LEVEL 86·5 AND FILTER POINT AT R.L. 78·0 PIPE A RECORDED 84·04, WHENCE LOSS OF HEAD = 2·46

Authorle 15-3-30.

DIAGRAM No. IA

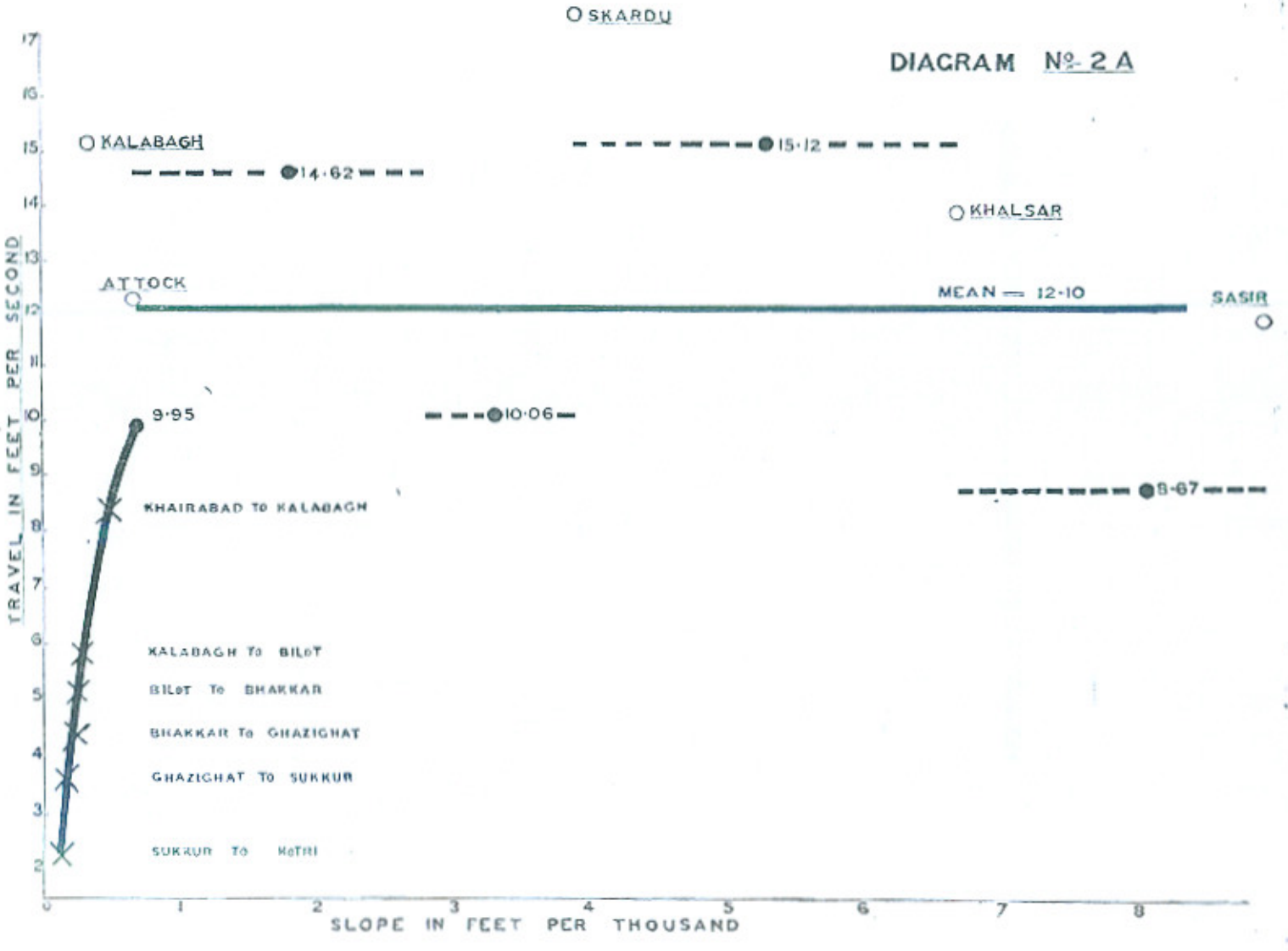
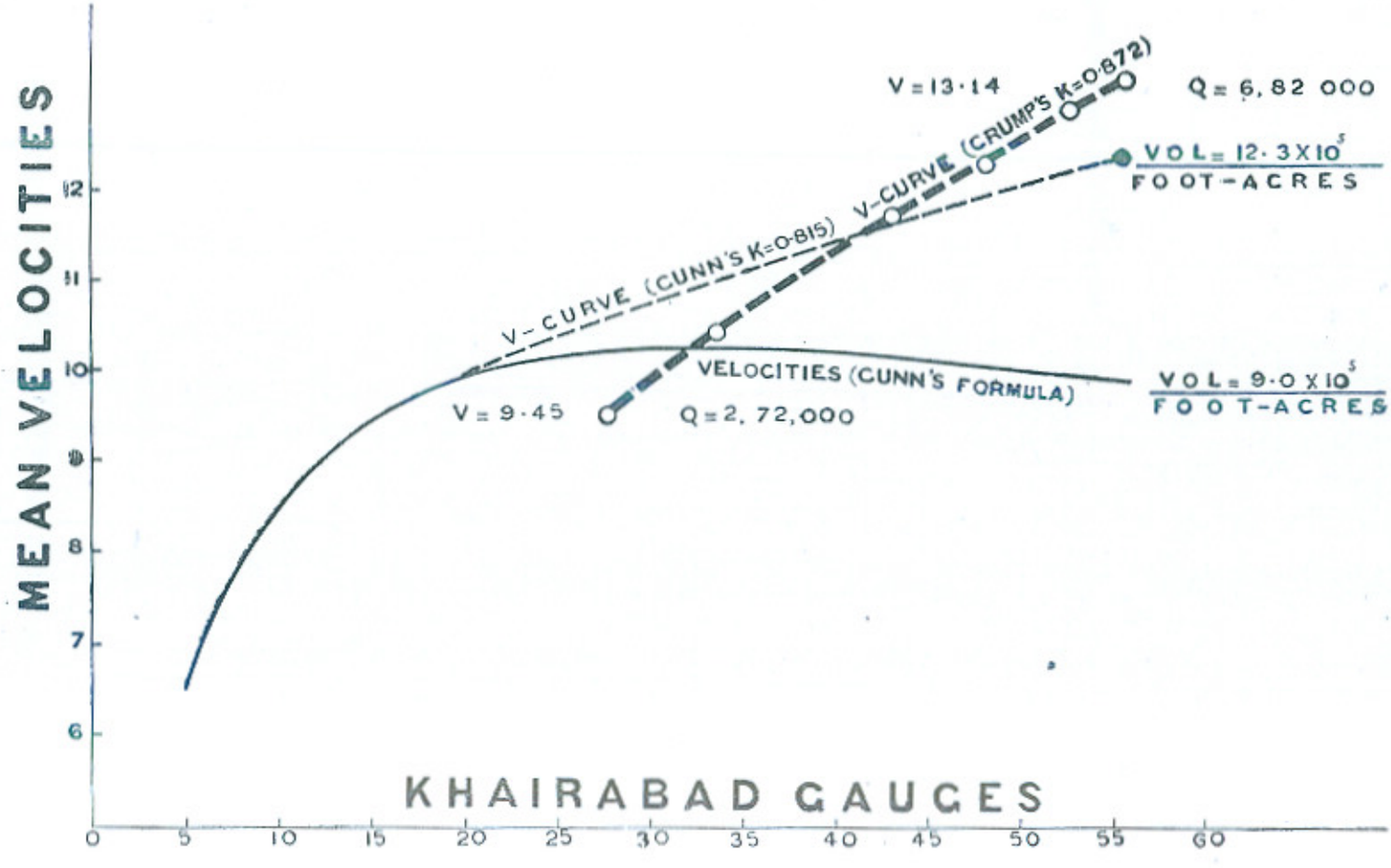

SKARDU
DIAGRAM No. 2 A
KALABAGH
14·62
15·12
KHALSAR
ATTOCK
MEAN — 12·10
SASIR
9·95
10·06
8·67
KHAIRABAD TO KALABAGH
KALABAGH TO BILOT
BILOT TO BHAKKAR
BHAKKAR TO GHAZIGHAT
GHAZIGHAT TO SUKKUR
SUKKUR TO KOTRI
TRAVEL IN FEET PER SECOND
SLOPE IN FEET PER THOUSAND

DIAGRAM No. 3A



DISCUSSION.

Mr. Crump, in introducing paper No. 134 on Mr. Gunn's behalf, remarked as follows :—

Mr. Gunn's paper, which when proceeding on leave he suggested that the speaker should introduce to this Congress on his behalf, presents for discussion the more technical features of his fuller official report to be found in Irrigation Branch Paper No. 32 which has recently been printed and circulated.

The report contains an interesting account of Mr. Gunn's expedition, last summer, to the Upper Shyok River and the Chong Kumdan glacier at its head.

On the 14th of August when the party, after making a survey of the lake, started on its return journey from the head of the Gapshan lake by way of the Dipsang Plain trade route, the glacier was still intact and was completely blocking the valley, but on the party's arrival three days later at Sasir Brangsa, a point on the Shyok some 10 miles below the dam, it was found that the dam had burst and that the entire contents of the lake had passed down into the Shyok valley. Mr. Gunn computes the volume of the lake at 10,95,000 foot-acres, and from this known volume he has in Appendix E of his paper calculated for each of five sites the value of the assumed constant $K = \frac{1{\cdot}486}{N}\sqrt{s}$ which enables him to evaluate the peak discharges and mean velocities given in Table 3.

From the point of view of Mr. Gunn's investigation the bursting of the dam occurred at a most opportune time in that it added greatly to the fullness and interest of the data collected by him. The speaker considered that Mr. Gunn was to be congratulated upon the thoroughness and skill brought to bear on the preparation of his report, the collection of data and the marshalling of results which, as he fully appreciates, are too often based on outside information of very questionable accuracy.

The speaker had little opportunity of discussing his paper with Mr. Gunn, and it is most regrettable in view of the many surprises he has sprung upon them that he is not present to-day to elucidate certain points and reply to the discussion.

Speaking as an independent member of this Congress, the first question he wished to take up is that of the data relative to the Khairabad Gauge at Attock. It will be noticed that the paper presents two independent sets of results for this site. One is based on Mr. Gunn's logarithmic formula on page 58, and the other on the known volume of the lake. In Plate XII, for instance, discharges shown by the small circles are calculated from the logarithmic formula, and give a peak discharge of about 5,11,000 cusecs. For the steady gauges of 27.5 and 28·0 feet which respectively preceded and followed the flood, Mr. Gunn has, however, abandoned his formula in favour of the value of 2,37,000 cusecs measured by the Discharge Division at Kalabagh on the

17th and 22nd of August, **i.e.,** before and after the passage of the Shyok Flood. The effect of this departure from his formula is greatly to increase the apparent volume of the flood, which, even so, is still nearly 20 per cent less than the known contents of the lake. The higher limit for which Mr. Gunn claims that his formula is reliable is only 3,00,000 cusecs, and the clear implication is that when extrapolated beyond this limit, the formula gives discharges which are too small. To confirm this the speaker had taken the cross section of the Khairabad site which Mr. Gunn used for his calculations of Appendix E, and had worked out the mean velocities for various gauges, by dividing his formula discharge by the corresponding sectional area. The result is shown by the full black curve in diagram No. 3A. It is seen that the mean velocity attains a maximum for a gauge of about 32 feet, and then falls off for higher gauges. The compact nature of the section considered renders such a result extremely improbable.

Turning now to the calculations of Appendix E, which are entirely independent of the logarithmic formula, the results give a peak discharge of 6,37,000 cusecs with a corresponding mean velocity of 12·28 feet per sec. These values are about 25 per cent. in excess of those given by the logarithmic formula. The calculation for K on page 71 is, however, made to depend on the Kalabagh value of 2,37,000 cusecs for the steady gauges of 27.5 and 28.0 feet which preceded and followed the passage of the Shyok Flood.

The speaker suggested that it would be more logical to ignore the Kalabagh figure altogether, and to make the calculations consistent among themselves by using the same value of K throughout. Adopting this method, he obtained from the cross section used by Mr. Gunn the following values :—

Mean gauge	=	27.75
Sectional Area	=	28,750 sq. ft.
R	=	35.7
$R^{\frac{2}{3}}$	=	10.84
$A R^{\frac{2}{3}}$	=	3,11,700

Replacing the Kalabagh value of 2,37,000 by $K A R^{\frac{2}{3}}$ the calculation for K becomes :—

$$38.32 \times \tfrac{2}{3} \times K = 10.95 + \frac{100}{24} \times K \times 3.117$$

giving K = 0.872 as against Mr. Gunn's value of 0.815.

This increase in K increases the peak discharge to 6,82,000 cusecs, nearly 34 per cent. greater than given by Mr. Gunn's formula and gives an initial and residual discharge of 2,72,000 cusecs as against 2,37,000 cusecs adopted by Mr. Gunn.

Mean velocities corresponding to K = .872 are plotted in diagram No. 3A. It is seen that they differ widely from Mr. Gunn's formula

values. In particular it may be noted that the peak-discharge velocity is now 13.14 as against 9.86 given by Mr. Gunn's formula. This gives a co-efficient of 0.73 as against 0.55 (suggested by Mr. Gunn at page 62 of his paper) for converting surface velocities to mean velocities.

In this connection Lala Nok Chand, now in charge of the Discharge Division, had informed the speaker that his estimate (based on floating-log velocities) of 8,17,000 cusecs for the record 1929 flood on the 28th of August, gave a value of N = 0.043 for an observed surface slope of 0.45 per cent. Applying the same value of N to the Shyok Flood he obtains a result of 6,96,000 cusecs which is in very fair agreement with the speaker's figure of 6,82, 000. It must, however, not be overlooked that Lala Nok Chand's first direct estimate of the peak-discharge of the Shyok Flood was 8,41,000 cusecs. This is no less than 65 per cent. in excess of Mr. Gunn's formula value of 5,11,000.

It will be appreciated that the observational data available for the Attock site is much fuller and more reliable than for the three sites on the Shyok, and if it appeared that he had unduly laboured this question his justification for doing so lay in the importance of bringing to light the great difficulties met with, even by skilled observers working under favourable conditions, of accurately computing the discharge of a large flood of short duration.

The most interesting results of Mr. Gunn's investigations are perhaps those presented graphically in his Plate VIII. A part of these results have been reproduced by the speaker in the Diagrams 1A and 2A with the additional further data supplied by Lala Nok Chand for points below Attock, both for the Shyok Flood and for the record flood which followed it a few days later. In Diagram No. 1A are shown three sets of curves. The horizontal scale common to all curves gives distances from Chong Kumdan Dam. The broken curves and isolated points show the magnitude of the peak discharges for the two floods. Solid lines indicate the absence of any addition of water from tributary streams. The travel curves show the progress of the mid peak plotted against the vertical time scale on the left. The slope of these curves gives the rate of advance of the peak. With time plotted vertical, increased slope means a lower speed of advance. The fine black curves are longitudinal sections drawn through the peaks of both floods. The upper line refers to the record flood and the lower to the Shyok. The slope of this curve indicates the general slope of the river bed from Kotri to Attock. Above Attock level data is very scanty, but he had extended the slope curve up to the dam by drawing a smooth free hand curve through the few points on the Shyok whose R. L. is known, and in Diagram 2A against, bed slope taken from L. Nok Chand's curve and is freehand extension of it, the speaker had plotted in black the rates f peak travel taken from the Shyok travel curve of Diagram 1A. The oints show the mean velocities given in the last column of Mr. Gunn's Table 3.

From the broken curves of Diagram 1A the general inference can be drawn that the rate of peak dissipation increases with bed slope. Comparing the two lines for the Sukkur Kotri reach, the peak discharge of the record flood is diminished to 76 per cent as against 81 per cent. for the Shyok Flood. In the absence of further data it would appear that the rate of peak dissipation is much the same for large as for small floods.

With regard to the rate of travel of the peak, it is easy to show that the speed of advance (**u**) of a steady discharge Q riding on a smaller steady discharge q is given by the simple relation.

$$u = \frac{Q-q}{A-a}$$

Where A and a are the average cross sections corresponding to the two discharges Q and q taken over the same reach. In saying this, it must be borne in mind that the several cross sections of which A and a are the means, must be taken at sufficiently close intervals, so as to include all areas that are inundated, regardless of their contribution to the discharge. In steep hilly country, for instance, where a river valley runs transverse to the rock strata, the existence of numerous lateral valleys and ravines would have a marked effect in increasing the areas inundated in a big flood. Or again, in alluvial tracts, the extensive lateral spreading in high floods would add greatly to the average area of cross section without contributing greatly towards increasing the discharge. In other words, the increased wetted perimeter may, in certain cases, result in a smaller value for a large than for a small discharge of the H. M. R. and therefore of the mean velocity. In such cases what may be called the mean velocity $V = \frac{Q}{A}$ is less than the mean velocity $v = \frac{q}{a}$ and it is found that u is still less than V; while normally V is greater than v, and u is greater than either V or v.

This elementary analysis may serve to explain why in the alluvial reaches below Kalabagh, the rate of advance of the Shyok Flood was slower than the mean velocity of flow, and also why below Ghazighat the Record Flood travelled more slowly than the Shyok Flood. Turning to Mr. Gunn's Plate VIII, it may also explain the slightly higher rate of travel from Diskit to Attock of the smaller flood of 1926 than that for the larger flood of 1929.

Turning to Diagram 2A (which deals only with the Shyok Flood of 1929) it is seen that the rate of travel below Attock bears a very definite relation to the bed slope of the Indus. Between Sasir and Attock on the other hand, no such relation can be traced. The rates of travel for various reaches range from 8.67 feet/sec. to 15.12 feet/sec. They appear to bear no relation to the general slope of the bed, although this varies from less than 1 to over 8 feet per thousand. The average value is 12. feet/sec. which is comparable with the calculated mean velocity of flow of Table 3 for Sasir and Attock and somewhat less than those for Khalsar Skardu and even Kalabagh.

Referring to Table 3, the general indication seems to be that the mean velocity of flow is independent of the general slope of the bed instead of varying as would be expected with the square root of the slope. It would appear however that the abnormal values of N which Mr. Gunn finds for Sasir and Khalsar result from his having calculated these values from the average bed slopes of Plates II and III instead of from locally observed surface slopes such as was presumably the case for the other three sites considered. The speaker would suggest that if Mr. Gunn had been able to observe local slopes at Sasir and Khalsar he would have found them to have values low enough to yield normal values for N. At page 55 of his paper he states that the flow in floods is extremely turbulent and influenced largely by local conditions. Again at page 6 of his official report he says that the bed consisting of large shingle and small boulders is unstable owing to the steep slope; that rapids of considerable length alternate with regions of smooth flow; and that the position of these is constantly changing. From this description it is obvious that the surface slope, (or more correctly the slope of the hydraulic gradient or total energy line), must vary greatly from point to point, and in comparatively quiet reaches must have values very much less than the average bed slope.

In steep river channels this variation in surface slope and hydraulic gradient is obvious to the eye at times of low supplies. In high supplies, it is commonly assumed that the slope is evened out. The speaker suggested that as regards the hydraulic gradient, *i.e.*, the rate of consumption of energy, the evening out is less than is apparent. Rapids and bars composed of heavy material are undoubtedly formed, eroded and reformed; and at each such restriction, although the standing-waves seen at low supplies are drowned out, concentrated losses amounting to several feet of head must still occur due to sudden changes of section and velocity. Between these points of sudden change of section lie comparatively quiet reaches whose depth and mean velocity is probably determined by the finer material carried in suspension. It would appear in fact, from the results now before them, that these relatively quiet reaches do not greatly vary, in regard to their mean velocities, from Sasir to Attock, and that the channel adjusts itself to an increase in general bed slope by the more frequent formation of bars and rapids, where the greater part of the energy losses takes place.

Mr. Khosla said :—

Mr. Gunn's highly interesting paper may be divided into two sections :—

(i) Flood prediction at Attock in the event of a burst up at the Chongkumdun or Shyok dam for different lake levels ;

(ii) a study of the conventional hydraulic co-efficient with special reference to the turbulent flow during floods.

As to the quantitative flood prediction, nothing better could be done with the data available and the result given by Mr. Gunn, will be of

lasting value in spite of some of the assumptions which he himself characterises as "bold in the extreme."

Mr. Gunn has brought out some very important points such as the 28′ cross slope in 1929 flood at the Khalsar Gauge site and the wide variation in the flood heights of 1926 and 1929 floods, the range being from 8·27 to 47·19 ft., following no definite order of distances.

The method of working from the storage volume of the lake to obtain peak discharges and gauges is highly ingeneous and a valuable contribution for future flood investigations.

But when he proceeds to the analysis of the co-efficient "N" and the factor applied for reducing surface to mean velocities on the basis of the available data some of the assumptions appear 'too bold'. Whereas, it may not be possible to agree with Mr. Gunn in his calculations of the peak discharge at Attock or the values of 'N' derived by him, there is no doubt that "his struggle to produce results with insufficient knowledge of the natu e of turbulent flow of water and un-reliable data" will go a long way in focussing attention and effort towards a clarification of our ideas about the fundamentals.

On page 55 Mr. Gunn has rightly "not attempted to draw a longitudinal section to show the high flood levels" but in his calculations for flood discharge he accepts the value of "S" based on low water levels as given in L. Sections of plates II and III. Again, he has not taken local values of S at sites of sections but has taken the mean of 12 miles at Khalsar gauge and of six miles at Sasir Brangsa. In view of the highly turbulent flow which gives a cross slope of 28′ at the Khalsar gauge cross section and of which an L. Section at high flood is considered as no correct or useful indication, it is open to question whether the low water slope can be taken even as a remote guide to what actually happened in the flood.

Mr. Gunn has placed too much faith in the logarithmic formula of page 58 for Khairabad gauge but the assumptions made therein must be remembered, to give it true weight. For the Khairabad gauge he has taken discharges observed at Kalabagh some 90 miles downstream and has allowed for a time lag which can at best be taken as hypothetical. His peak discharges are extrapolated beyond the range of observations. With the best of results, this equation can only be an approximation and the deductions therefrom can be an indication as to the accuracy of other data and not a definite check.

On page 60, Mr. Gunn has taken Manning's formula as a basis for a study of co-efficients in turbulent flow. He has assumed

$\frac{1{\cdot}486}{n} \times \sqrt{S} = K$ a constant without justifying his assumption.

On page 62, he says that "as may be expected the co-efficient K is not a true constant for the whole range of the flood at any site but varies with the degree of turbulence." Reference is here

invited to page 243—246, Vol. IV of the Miami Conservancy Distirict publication "Calculations of flow in open channels", wherein the relative merits of the Manning formula as against Kutter's have been discussed. This formula gives consistent results for values of H. M. R. up to 4'. For higher values the slope largely affects the results. The 'C' of Chezy in $V = C/\overline{RS}$ is the same as $\frac{1{,}486\ R^{1/6}}{n}$ of the Manning formula. Plotting C as abscissa and R as ordinate, it is at once apparent (Figs. 61 and 62) that there is increasing divergence between values of C as derived from the two formulae. For n = ·030, the two agree for slope of 10 ft. per ‰ For n = ·010, the two agree for S = ·000025. For slopes considered in this paper the variation in value of C by the Manning and Kutter's formulae is not large, when n = 0·030, but for flatter slopes or for higher values of 'n' like 0·08 this variation may be considerable.

For purposes of Table 3, Mr. Gunn has made allowance for the normal river supply before the flood came on. This is, however, a very uncertain factor. In connection with the flood investigation for the Haveli Project, the question of what to accept as the normal supply for purposes of comparing the foot acres passed at different sites between the flood peak and the normal, is offering some considerable difficulty. A small mistake in arriving at the correct normal will throw out the value of K and consequently of N.

$$K = \frac{\text{Volume of lake}}{\left\{\begin{array}{l}\text{Area of time dischage curve}\\ \text{at any site between peak and normal}\\ \text{river.}\end{array}\right.}$$

$$= \frac{\text{Volume}}{\Sigma A}$$

Supposing ΣA to be exaggerated, K will be diminished.

Since $n = \frac{1{\cdot}486/}{K}$, therefore 'N' will increase.

For Sasir Brangsa and Khalsar, Mr. Gunn has ignored the normal flow altogether. Perhaps his local knowledge justifies this step. But if there was any discharge passing, that volume if deducted from the volume of the lake, will increase K and therefore reduce 'N'. The high co-efficient of 0·1651 and 0·0872 may at least in part be due to this omission.

In view of the assumptions referred to above it is not possible to place implicit reliance on the peak discharges or the values of 'N' deduced. The mean velocities will be effected in consequence.

The speaker fully agreed with Mr. Gunn in his contention that the co-efficient of 0·9 used to reduce surface to mean velocities is very doubtful but the extremely low value of 0·55 deduced by him cannot be accepted

as a nearer approach to truth as the fundamental assumptions lack justification.

Mr. Gunn's paper also helps to remove the general misconception that the peak discharge of a flood at one place is necessarily the same lower down irrespective of the distance. The peak discharge decreases as the flood travels down, the duration increases but the foot acres passed at each site above the normal are very nearly the same. Investigations in connection with the record flood of 1929 support this fact in the cases of Indus, Jhelum and Chenab.

Mr. Montagu had no wish to belittle Mr. Gunn's achievement in sounding the Lake Gapshan but he had certain criticisms to level at the calculations for discharge.

2. There were at least three classes of flow. *viz.*, the viscous (true stream line); turbulent (silt bearing): mechanical turbulence, for want of a better name (flow in which part at least of the "slope" is due to falls and the *mechanical* turbulence that results).

The slopes quoted as "mean slopes" on page 54 by Mr. Gunn emphatically belong to the last class of slope and certainly are not normal slopes such as are applicable to Manning's formula for "normal" flow.

3. Mr. Gunn appears to have taken no account of the important effect on flood flow of the velocity reaching the "Minimum Energy" point. Should this state of affairs occur then any obstacle will result in considerable heading up which will accelerate the approach of the flood but retard the peak.

That this appears to have occurred is evidenced by the Table I on page 56 of which extracts are now given comparing the two floods of 1926 and 1929.

	Skardu to Bunji.	Bunji to Attock.	Total.
1926 ..	8 hours.	30½ hours	38½ hours.
1929 ..	14 hours.	29 hours	43 hours.

The smaller flood has definitely taken longer than the larger.

4. If Mr. Gunn confined himself to a simple statement of volumes in the Lake Gapshan on given dates, the only question at issue would be the accuracy of his observations, but his attempts to confirm his observations by other evidence leads to contradictions.

What does Mr. Gunn mean by "normal" inflow? Does Mr. Gunn mean "average"? If so an average of 0·9 feet a day means 328·5 feet year. Add to assumed level just a year ago (1928) of 15,850 and the lev in 1929 is 16,180 against the given level of 15,885 at which the la burst.

Either Mr. Gunn's estimate of the volume of the lake is wrong, or his observations and deductions about the average inflow are inaccurate.

5. Mr. Gunn's attempt to co-relate the inflow into the lake with the temperature and discharge curve at Khalsar is neat, but leads to more inconsistencies. From 1st to middle of August, the temperature discharge curve indicates a flow in the Shyok of about 40,000 acre feet per day. On page 56 Mr. Gunn intimates an inflow to the lake of 6,580 acre feet. He saw no reason why the two discharges should be in any way co-related; however 6·580 is 16 per cent. of 40,000.

But this gives a rise during the period of *biggest inflow* of 0·55 feet per day against the 0·9 feet arrived at by different observations.

Turning now to Table II on page 57 and converting the cusec discharges into acre feet it is found:—

	Khalsar.	Gapshan.	Per cent.
June ..	60,000	5,000	8·3
July ..	1,320,000	115,000	8·7
August ..	2,100,000	183,000	8·7
September	720,000	63,000	8·7

Why should Mr. Gunn suddenly vary the percentage from 16 per cent. to 8 per cent? It follows that a trifling error in the per cent. relation will result in a considerable error in the estimate of Lake Gapshan volume, even if it is assumed (which the speaker did not admit) that there is any comparable relation at all.

6. Another speaker will deal with the logarithmic equation on page 58 so he would pass directly to the application of Manning's formula to evaluating the discharges, on page 60.

In Manning's formula S, the slope is that of the total energy line and represents the loss due to friction arising from the periphery and not from energy lost in standing waves and genuine mechanical turbulance.

It is not even the slope of the surface unless the surface and T. E. line are parallel. The slope of the surface in flood is therefore useless for the purpose. It is even more useless to take the slopes mentioned on page 54 which appear to be purely arbitrary averages of differences in levels.

7. The assumption that $\frac{1{\cdot}486}{N} \times S^{\frac{1}{2}}$ remains constant is of course fundamentally incorrect.

The Table III on page 61 is instructive in this respect.

(i). Generally speaking, Kalabagh is the only site where Manning's formula is in the least degree applicable.

(ii). At Attock the slope appears definitely to be too low and heading up appears to have taken place above,

(iii). The other slopes are far too high and indicate that falls and mechanical turbulance existed. This is borne out by the resulting N. N as such cannot possibly vary from 0·1651 to 0·0212. Clearly the slope taken in the first cases is excessive and so N must work out too big to compensate the value of K.

(iv). Again it appears improbable that the velocity should *rise* from 12 f. p. s. to 15 f. p. s. as the slope falls.

(v). The one exception to this is the velocity at Skardu. Cross sections at site were not given; so the speaker was unable to look for a physical explanation.

He suspected an arithmetical error, so looked through such figures as were given.

On plate XV compare stages 2 and 3.

The arithmetic is correct, but obviously there is an observational error. If stage 2 is 57,000 square feet and stage 3 is 44,000 square feet how can W. P. be 2,220 and 2,370 feet respectively?

Clearly the Skardu observations and consequent calculations are definitely wrong.

8. Mr. Gunn draws a misleading conclusion in suggesting the variation in N is due to turbulance. It is due to his assumption and his application of Manning's formula being unjustified.

9. The speaker endorsed Mr. Gunn's suggestion for further investigation and defined the problem as an enquiry into flood transmission by waves which could be carried out in the laboratory by measuring the rate of rise and time lag of an efflux from a measured tank, due to the influx of a known discharge.

L. Nok Chand, supplied a written communication in which he stated:—

That the Author expected someone to carry out further investigations of correct co-efficients for mean velocities. Though not impossible, this problem is practically difficult for high floods at places like Attock and Kalabagh. At these places even a motor launch will not be able to remain steady for accurate measurements of mean velocities. I tried to observe mean velocity at Attock by lowering the meter from the bridge, but the turbulance and the high velocity would throw up the meter to surface and would not allow it to sink although the weight attached to it was 27 lbs.

At Kalabagh the velocities were so high in last year's flood that even the ferry steamer failed to go upstream. Nothing short of a powerful launch would suffice for accurate observations of velocities and soundings for these sites during floods.

The reduced datum levels of water surface for Skardu Bunji and Chilas are not given by the Author, and it is not possible to get any accurate longitudinal slope from point to point. The slope for the reach Sati to Diskit in higher altitudes than Khalsar is given as 19 feet per mile or roughly 8 feet in 2,000 feet length. If it is assumed to be the same in the vicinity of Khalsar the transverse slope of 28 feet in 2,000 feet

width is nearly 4 times the longitudinal slope which seems unlikely. Probably the flood marks on one of the banks were inaccurately observed. This is confirmed by the author's remarks on page 60 where he says that no marks were visible on the right bank at Khalsar.

The Author says on page 65 that flood marks at any one place noticed in one year cannot be taken as a guide for the magnitude of future floods. This is because there are so many tributaries with uncertain contributions, and will mean that a gauge at Skardu will be a better include of the floods than one at Khalsar, because supplies at Skardu will include two big tributaries *i.e.*, the Nabra and the Shigar.

The least time taken from Khalsar to Leh by a *dak* runner being 12 hours, and the time taken by flood to pass from Khalsar to Skardu being 16 hours, the warnings from Skardu will reach the plains at nearly the same time as those from Khalsar.

The Author has given a discharge curve for Khalsar. But he does not supply the details of his observations to show how the mean velocities were arrived at : or whether they are all based on his hypothetical coefficients. Since the Author has fixed a gauge at Khalsar, it would have been better if he had calibrated this gauge, and given a comparative curve of Khalsar and Attock gauges.

In working out his logarithmic formula the Author has based his calculations on a curve of Attock gauges plotted against discharges at Kalabagh which is 100 miles downstream. This curve when plotted differs from year to year and any mean line as a fairly accurate guide cannot be chosen. The Author has not said what time-lag he assumed between Attock and Kalabagh which in itself is very variable.

The discharges taken for Kalabagh are only for a range of discharge up to three hundred thousand cusecs and it is not safe to exterpolate a curve for nearly double this supply. Nor can the formula be considered accurate for supplies beyond the range of observations when it involves so many uncertain factors.

Local heading up at Attock taken as 5 feet by the Author cannot always remain constant. The amount of silting or scouring in the river bed at Attock at any period is a variable quantity whose value cannot be stated without actual measurement. But Attock is simply a gauge site and no soundings or discharges are observed by the Discharge Division at this site. Any arbitrary assumption about the bed at Attock will render the formula inaccurate and make its utility very doubtful.

The Author does not give the maximum lake level of which he found traces available. Such information would have been of value. During the record flood at the end of August, 1929, accurate surface velocities were observed at Attock, and gave a value for 'N' of 0·043 and S=0·00045. Working from this discharge the writer found that the Shyok flood discharge was nearly 6,96,000 cubic feet per second against the 5,11,000 worked out by the Author's formula.

The future damming up of the Indus supplies may not be at the place of last year and may take place in some other tributary lower down such as Nubra or Shigar which have glaciers of very large magnitude

though not yet explored. If so, a gauge in the Gasphan lake will be valueless, and all the warning arrangements from Khalsar of no avail.

Mr. Gunn in replying to the discussion, said—The Author wishes to thank Mr Crump for the care he has given to introducing the paper and to criticising the results set forth in it.

It may clear matters somewhat if it is again emphasised that while the figures are correct so far as it lay in the author's power to observe them, the data are not sufficient to warrant any definite conclusion being accepted finally.

In regard to the Kalabagh discharge formula it was the best the Author could derive with the data at his disposal and can only be applied to a river bed free from silt. Hence the acceptance of the observed discharges before and after the flood. It must also be remembered that the volume of the lake is only an approximation, and this combined with the absence of any positive depth measurements at Attock, led to the acceptance of the approximate figures in the table.

Mr. Crump has taken the study of the gauge discharge curve at Attock a step forward and produced a much more reasonable co-efficient for reducing surface to mean velocities, but in doing so he produces also the result that the discharge of the Indus was 2,72,000 cusecs instead of the 2,37,000 reported an excess of over 10%. The question is still open for further research.

Mr. Crump's study of the movement of the flood below Attock is interesting and worthy of close attention.

Mr. Khosla's kindly criticism calls for little comment. The Author would only remark that owing to the nature of the flow all hydraulic flow formulae are equally inapplicable and Manning's seemed the simplest and was adopted.

Mr. Montagu appears to have misunderstood some points in the paper. The particular " normal inflow " might more properly have been called inflow to be expected in normal weather. Obviously the rate of rise depends on the surface area of the lake and decreases for the same discharge as the water level rises.

The Author would also point out that he was not attempting to confirm his observations, but to see how far the reports received tallied with the observations made.

Mr. Montagu's difficulty regarding the sudden change in percentage of discharge may be cleared by a reference to table 2 where it can be seen that the Khalsar discharge is in cusecs and not in foot acres.

The author is much obliged to Mr. Montagu for pointing out the apparent source of error in the Skardu observations, he will investigate the matter on his return to India. He had also taken much time checking the arithmetic.

L. Nok Chand's remarks call for no special reply. The Author would merely remark that his statement regarding flood marks on the right bank was meant to refer to the intermediate stages of the flood and not to the maximum.