DISCHARGE OBSERVATIONS.

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Object of observations—Regulation—Distribution and measurement—Discharge table—Silt waves—Standard notches—Discharge diagrams—Conditions on distributaries—Collection of data—Errors in observations—General conclusions—Summary.

Object of Observations.

The object of observing discharges of canals is two fold; first for purposes of regulation, distribution, and measurement; and secondly in order to obtain information regarding absorption, and the laws which govern the flow of water and transport of silt in canals. This information furnishes data on which designs for new canals are based.

Regulation.

For regulation, it is necessary to know, as accurately as possible, the rate at which the discharges vary with the gauges for the parent channel and its branches or distributaries. The actual discharge which a channel is carrying is only of importance when large alterations in supply are being made, and its importance depends on the ratio of the size of the branch or distributary to that of the parent channel. Thus, in the case of a main channel bifurcating into branches, the regulation must be done on gauges fixed at the heads of the channels. Discharge tables exist for these gauges, and are corrected once or twice a month as the result of discharge observations made either near the gauge, or at some site lower down where the conditions are more stable. Between these times of observation, the actual discharge may differ widely from the tabular discharge if silt has been deposited or scoured in the interval, though the increment of discharge, for a small increment of depth, will not differ greatly if only a few inches of silt are deposited on or scoured from the bed. The officer in charge of a branch does not therefore ask for a certain total quantity of water, but for his present supply to be increased by a certain amount, and since he knows the increase on his gauge that will be required to effect this increase in supply, he simply asks that the gauge may be raised by so much. The officer in charge of the

main line may then reduce this to cusecs to find out what increment he will require at the head gauge of the main channel, or, if the increase asked for be small, he omits the intermediate steps and from experience judges the increase in gauge required in the larger channel. In other words, regulation is done on gauges, and except for large variations in supply discharge tables are of little value.

Distributaries are usually run with a full supply, and small differences in gauges will not ordinarily affect the branch gauge. All that it is necessary to know, therefore, is the full supply discharge or the increment on the branch gauge equal to this supply. What is wanted then is a mean discharge table, correct to about five per cent. for large channels, and ten per cent. for small ones, from which the rate of variation of the discharge with the depth, for any given depth, and the approximate discharge can be obtained.

Distribution and Measurement.

For the purposes of distribution and measurement of water, it is necessary to know the actual quantity flowing in the various channels, and to know this not merely at intervals, but continuously, while to regulate the flow it is necessary that a relation between the gauge of a channel and the discharge should be established, though this correspondence need not and cannot be very exact. To measure the quantity of water accurately sites should be chosen where the relation is stable and measurements made at these points, or, if this be inconvenient, the discharge table for the head gauge should be corrected by comparing it at intervals with the table for the more stable gauge. On main canals and branches this is what is generally done, but sites are frequently chosen, not because they are places where stability exists, but because they are either at the beginning of a division, or because, if the better site were chosen, it would involve discharge measurements of subsidiary channels or outlets higher up, in order to arrive at the quantity of water entering the channel or division. In the writer's opinion, much greater accurancy would result if the more stable sites were chosen, and if the discharge at the head were inferred by deducting any draw off between it and the site.

Discharge Tables.

Free falls are points where the relation between the discharge and the gauge is not affected by alterations in the depth, slope, or width of channels, and by calibrating such falls we obtain what is required—a constant discharge table. If free falls do

not exist, then drowned falls may be used, either as such, or by the addition of diverging walls downstream so that they may be independent of the downstream water level, and work as free falls for very small differences of level upstream and downstream. If no fall at all exists, then a flume at some site well removed from the head of the channel may be used. Of these, the discharges of free falls cannot be in any way affected by silt, while the discharge of drowned falls may, by a rise of the bed downstream, be so affected, though not if diverging walls have been added, so long as the minimum working head is available. Flumes may be affected by a general rise of bed level.

Having fixed on as suitable a site as possible, and the coefficients of discharge for the falls being unknown, a certain number of discharges must be taken, and a discharge curve drawn. Once this curve has been satisfactorily determined there is no object in taking any more discharges, except in cases where, as mentioned above, a rise in the bed downstream of the fall occurs. Correction factors, however, should not be applied, as the result of a single discharge, to a table prepared in this way.

As an example of how a table can be established for a fall discharge observations taken by Mr. W. S. Braybrook in a flume above the fall in mile 7 of the Bhatinda Branch and referred to a gauge at the fall, have been plotted logarithmically on the attached diagram, (Plate No. 1). Practically all the points lie very close to the line represented by the equation

$$Q \text{ (Discharge)} = 60\ G^{1\cdot88}$$

This agreement indicates a small personal error, apart from the fact that one would expect to get less variation in a flume where there was little or no silt than in an unlined channel where the bed was covered with silt waves or dunes. The mean error is only 1·67 per cent, and with the exception of two observations all discharges are within three per cent. of the discharge given by the above equation. This uniformity clearly shows that the relation between the discharge and the gauge does not vary, which is what would be expected at a free fall. The fall consisted of six notches of the usual trapezoidal form, so that the formula

$$Q = 5\cdot35\ c\ D^{\frac{3}{2}}\ (l - \cdot4\ n\ D)$$

was applicable. Assuming that the zero of the gauge was at sill level G might have been substituted for D, and values of the

coefficient worked out for several depths, giving as resulting values

$$G = 7 \text{ ft.} \quad c = 0{\cdot}95$$
$$G = 5 \text{ ft.} \quad c = 0{\cdot}945$$
$$G = 3 \text{ ft.} \quad c = 0{\cdot}848$$

A constant value for c was not to be expected, since the notch was not of similar form for different depths. The fact that an equation of the form $Q = K D^n$ was applicable is interesting, and suggests the possibility of designing a notch for which the discharge would vary in exactly the same manner as the discharge of the channel varies. The extraordinarily high value for c is also of interest, and the ordinary value (0·75) used in designing notches for large channels would appear to be much too low. The notch apparently had to be tightened at one time

Silt Waves.

On the same diagram, a few discharges taken above the fall at R. D. 69,000 on the Jhang branch of the Lower Chenab Canal have been plotted. Further observations were available to the writer but were considered doubtful, as the dates coincided with the opening of two silting tanks between the discharge site and the fall. There was no flume at this site, and silt waves caused large variations in the depth measurements ; in some cases there was as much as two feet difference between depths measured on the same longitudinal section. The trouble about silt waves is that they introduce an error which is always in one direction. Assuming that the depths at the several points of observation are fairly represented by their mean, the velocity rod used must be less than the least depth, and therefore the observed velocity is greater than that corresponding to the mean depth, even supposing that the water below the crests of the waves is moving in the same manner as the water above the crests, but this is certainly not the case, as eddies exist in the troughs of the waves which do not move with the general stream and may even be stationary. This source of error can only be eliminated by constructing a flume, though even in a flume silt waves often occur, and to entirely eliminate them the bed of the flume should be higher than the silted bed of the channel.

Standard Notches.

Instead of constructing a flume, however, a better solution of the difficulty would be the adoption of a standard type of notch. Since there must be an integral number of notches, the

sill level of the fall would not be exactly at the bed level of the channel, unless the discharge of the channel were an exact multiple of the notch discharge. The difference would not be great however, and would be of no practical importance, since the only effect would be to cause a slight heading up for low supplies. It would be necessary to construct the approaches to the notches so that the area of the stream at the gauge would be always related in the same way to the waterway of the notches.

Discharge Diagrams.

Returning to the fall on the Jhang Branch, the discharge and corresponding gauges have been plotted, and the line drawn represents the tabular discharges. The original table was checked by observations other than those on the diagram, and the points now plotted are close to the line, which, however, is so short that its equation cannot be accurately determined, but is approximately

$$Q = 50{\cdot}6\ G^{1{\cdot}86}$$

The downstream water level at this fall is about two feet above the sill level when the full supply is running, or in other words the submergence is less than a quarter of the full supply depth. Submergence to this extent will not cause the discharge to vary greatly, if at all, from that of a notch discharging freely into air, since, according to Herschel, for this degree of submergence the equivalent head for a free notch would be 0·96 to 0·984 of that for the submerged notch. Treating the notch as free and applying the formula

$$Q = 5{\cdot}35\ D^{\frac{3}{2}}\ (l + {\cdot}4\ nD)$$

we get the following values for c.

G or $D = 9$ ft. $c = 0{\cdot}9$
G or $D = 8$ ft. $c = 0{\cdot}87$.

This fall consists of eight trapezoidal notches, and drawings of these notches and of those on the fall on the Bhatinda Branch are attached (Plate No. 2). In this case also the notch had to be tightened.

On the same diagram discharges taken in flumes on the main line of the Sirhind Canal and on the Patiala and Abohar branches are plotted, and in all cases there was very little silt on the flumes. Conditions on the main line would appear to be very stable, but considerable variation is apparent on the Patiala branch, though under favourable conditions the results indicate

that flumes might be treated as points where the relation bet the discharge and the gauge was stable. It would of cours necessary to take regular discharges at such sites, but cons able variations from the previously established tabular disch should be treated with suspicion.

In practice, however, discharges at flumes are gener used for correcting a discharge table for a gauge at the head a channel, or at some site where it can be easily read, but conditions at such places, particularly if the gauge be immediat below a regulator, may vary, and it would obviously be better observe the gauge at the flume daily, and calculate the discha from the table for the flume site, in order to know accur the quantity of water which has flowed in the channel dur the month. In the case of large channels it would prob not be difficult to arrange to have any particular gauge obser regularly, although it might be difficult to do so on distributa or minors without increasing the staff.

Conditions on Distributaries.

The conditions on distributaries and minors differ fro those on main canals. The discharge sites are almost alway near the head, and the discharge observations are much less accurate and are not so frequently observed. Relatively, silt affects the relation between the gauge and discharge to a greater extent in small than in large channels. On many channels, however, falls exist within a few miles of the head and provide a means of measuring the discharge accurately. The chief reason why these are not used is that between the head and the fall there may be several outlets the discharge of which is not accurately known, while another reason is that the falls cannot be used for measurement until tables have been prepared for them. The discharge of the outlets will not be considerable, however, unless the fall is far from the head, when the outlets can be replaced by modules or semi-modules. A standard type of weir or notch can be adopted for which co-efficients can be accurately determined by tank measurements or otherwise, and if it is not possible to have the gauge read daily, it can be read two or three times a month and used for correcting the discharge table for the head gauge. Apart from other considerations, the saving of time spent by the Sub-Divisional Officer, zilladars and others in making observations is a strong argument in favour of the use of falls.

In addition to obtaining a continuous record of the quantity of water entering a distributary, it is important to be able to determine by inspection at any particular time whether sufficient

s reaching various points on the channel, more particularly l. Falls probably occur at one or two sites on the l, and, if of standard pattern, afford an easy and accurate d of determining the discharge. At the tails of channels designed to be independent of the water levels in the courses can be used.

ection of Data.

The collection of information regarding the general laws ming the flow of water and transport of silt in channels idental to the main purpose of ascertaining the discharge. so obtained from one observation and noted in a discharge is, however, seldom compared with similar data obtained other observations, though there must be an immense ction of such information filed in the various offices of the rtment which, if analysed, might add considerably to our wledge of hydraulics.

rors in Observation.

Errors due to silt waves on the bed of a canal have already en mentioned. Another error may occur in measuring the pth, through heading up on the staff, when he difference in vel above and below may, with a broad rod, mount to nearly e velocity head. A flat iron rod with a circular plate at the base more satisfactory than a wooden rod, and the reading should e made at the side of the staff, instead of either at the upstream r downstream edge. The width of a channel can be accurately easured if light wire ropes are tightly stretched across it.

The least satisfactory observation is as a rule that of the slope, which, though not required for the determination of the discharge, is of the first importance when investigating the laws governing the flow. It is often not observed in large channels and almost never in small. The slope which is observed is that in the neighbourhood of the discharge site, but it is not recorded whether it is constant for a long length of the canal. The difference to be observed is always small and pulsations of the water surface will affect the readings. If gauge wells do not exist pegs must be fixed at the water surface, and errors may occur in levelling between these pegs. Gauge wells should be constructed at the sites with gauges having their zero at exactly the same level, while in addition to observations at these wells, a gauge or gauges a few miles from the site, should also be read and recorded. Two hooks should be

fixed on each gauge in order to obtain a mean reading eliminate the effect of pulsation.

General Conclusions.

The writer is indebted to Messrs. Colbourne, Curry Bur Singh for the data given in the attached statement* regard discharge observations on the Sirhind and Lower Chenab can while the data for the Lower Jhelum Canal have be borrowed from Mr. Woods's paper on distributary head (Punjab Engineering Congress 1916), and while admitting th these observations may be subject to error, certain gener conclusions may be drawn.

(1) The slope and critical velocity ratio are not greate in the hot than in the cold weather, although there is a greater total load of silt in the hot weather.

(2) The critical velocity ratio for the main line of the Sirhind Canal is always lower than that of the branches, while on the Jhang branch of the Lower Chenab Canal, it is higher at R. D. 69,000, than at R. D. 218,000, and 279,000, although the quantity of silt must be the same in the first case, and nearly the same in the second.

(3) The ratio of the depth to the bed-width is low, so that the proportion of the wetted perimeter occupied by the sides is small, on the average about 0·14 of the whole, and consequently differences in the rugosity of the sides cannot be held accountable for the large variations in N, namely from 0·013 to 0·029 (mean value 0·02), and alterations in the disposition of the silt on the bed must be held responsible.

(4) Kutter's N and the critical velocity ratio are not independent variables, but vary inversely with each other. With the aid of a paper† by Grove Karl Gilbert describing experiments made on small channels transporting sand, the writer has attempted to find an explanation for this, and his results show that the critical velocity ratio is a measure of the quantity of the bed silt and not of the total silt

* See pages 58 - 60.

† United States Geological Survey—Professional Paper No 86.

load.* A final solution can, however, only be arrived at by making accurate and systematic observations on canals, and analysing the results.

What is required is to concentrate attention on one branch with its distributaries and make continuous observations on all the channels. A branch and distributaries on both of which there are a number of falls should be chosen, the falls standardized, and arrangements made for observing slopes throughout the system accurately.

The column 'absorption' in statements regarding consumption of water includes all observational errors, and since the absorption is usually only a small fraction of the total discharge, and can only be accurately measured if the discharges, of which it is the difference, are accurately known, a minus absorption is not uncommon. It would be better to determine absorption where such measurements are possible, *i.e.*, where falls exist, and from the result deduce the absorption at sites where accurate measurement is impossible. A column headed 'observational error' would then be necessary in statements.

Summary.

To sum up, the writer advocates a choice of sites on canals for discharge observations where it is possible to establish a stable relation between the discharge and the gauge, the best sites being those at which falls occur, while the best solution would probably be to rebuild the notches at such falls to a standard pattern. Ordinarily, such sites should be chosen irrespective of other considerations, and discharge tables for other less stable, but necessary gauges deduced from the table for the fall; while in order to arrive at reliable information regarding the flow of water in canals, transport of silt, and absorption, one or two systems of channels, on which a number of falls exist, should be chosen and studied.

* See Appendix on page 61.

TABLE No. I—OBSERVATIONS ON CANALS.

Name of channel and reduced distance (R. D.) of discharge site.	Date of observation.	Slope ‰ S.	Depth D.	Gauge G.	Mean velocity V.	Ratio Depth / Width R.	Critical velocity ratio C. V. R.	Kutter's N.
SIRHIND CANAL—								
Main Line, R. D. 132,000 ...	6—16	·13	11·76	11·82	3·25		·79	
	7—16	·12	11·23	11·21	3·31		·83	
	6—16	·12	10·98	11·00	3·30		·86	
	10—16	·12	10·96	11·09	3·32		·85	
	11—16	·13	10·00	10·00	3·09		·83	
	11—16	·13	8·65	8·70	3 05	·06	·87	
	11—16	·13	8·50	8·54	2·88	to	·86	·021
	12—16	·13	8·45	8·43	2·90	·08	88	to
	9—16	·12	7·99	8·03	2·90		·93	·025
	12—16	·13	7·91	7·91	2·82		·90	
	9—16	·14	7·21	7·27	2·87		·96	
	1—17	·11	7·01	7·07	2·63		·90	
	1—17	·11	6·99	6·98	2 55		·88	
	8—16	·10	5·61	5·62	2·52		1·00	
Bhatinda Branch, R. D. 32,000 ...	12—16	·10	6·28	6·35	3·37	·075	1·23	·017
	6—16	·10	6·20	6·25	3·26	to	1·20	to
	9—16	·10	5·82	5·90	3·16	·037	1·20	·019
	11—16	·10	3·14	3·50	2·40		1·14	
							0·91	·018
				9·61	3·90		1·08	to
							1·05	·020

Discharge Observations.

Patiala Branch, R. D. 15,000 ...	6—16	·15	9·61	9·61	3·90		1·08		
	6—16	·15	9·60	9·56	3·90		1·08	·018	
	7—16	·15	9·56	9·56	3·79		1·05	to	
	11—16	·20	9·36	9·18	3·83	·128 to 0·1	1·08	·020	
	11—16	·20	9·25	9·25	3·89		1·11	·022	
	12—16	·15	9·01	8·80	3 96		1·14	·018	
	9—16	·15	8·80	8·80	3·90		1·15	to	
	10—16	·15	8 25	8·25	3·55		1·09	·020	
	9—16	·15	7·55	7·40	3·56		1·15		
Abohar Branch, R. D. 1,000 ...	2—17	...	7·22	7·22	3·46		1·15		
	1—17	...	6·90	6·90	3·53		1·21		
	6—16	...	6·60	6·60	3·35		1·18		
	9—16	...	6·52	6·50	3·36	·066 to ·058	1·20		
	11—16	...	6·37	6 40	3·35		1·21		
	11—16	...	6·30	6·35	3·26		1·18		
	7—16	...	5·00	5·00	3·14		1·32		
	9—16	...	4·30	4·30	3·00	.04	1·38		
Bhatinda Branch, Mile 33 ...	6—12	·18	6·98	...	3·22	0·1	1·11	·019	
	7—11	·16	5·12	...	3·26		1·21	·017	

TABLE No. I.—OBSERVATIONS ON CANALS—*concluded.*

Name of channel and reduced distance (R. D.) of discharge site.	Date of observation.	Slope $\frac{1}{S}$	Depth	Gauge	Mean velocity	Ratio $\frac{\text{Depth}}{\text{Width}}$	Critical velocity ratio	Kutter's
		S.	*D.*	*G.*	*V.*	*R.*	*C. V. R.*	*N.*
LOWER CHENAB CANAL.—								
Jhang Branch, R. D. 65,000 ...	1—08	·12	8·10	8·55	3·05		0·965	·025
	2—08	·18	8·10	8·76	3·14		0·975	·024
	5—08	·22	7·53	8·60	3·15	·075	1·02	·026
	11—07	·18	7·40	8·62	3·40	to	1·12	·021
	12—07	·18	7·40	8·35	3·20	·065	1·06	·024
	3—08	·17	7·30	8·95	3·77		1·26	·018
	10—07	·18	7·20	8·48	3·63		1·22	·018
R.D. 218,000 ...	4—08	·17	8·64	8·77	2·72	1.0	0·82	·028
	4—08	·19	8·36	8·44	2·75	to	0·84	·029
	6—08	·16	7·26	8·65	2·74	·085	0·92	·027
R. D. 277,000 ...	4—08	·15	7·80	8·40	2·65	0·1	0·84	·025
LOWER JHELUM CANAL.—								
Northern Branch, R D. 307,200 ...	6—14	·20	4·40	...	2·37		1·09	·021
	6—14	·20	4·30	...	2·05	·09	0·96	·0235
	6—14	·18	3·80	...	1·92	to	0·97	·023
	6—14	·20	3·70	...	1·90	·1	0·97	·0235
Southern Branch ...	12—15	·10	4·22	...	2·79	·056	1·31	·013
KIRANA.—	5—14	·10	4·20	...	1·81		0·86	·018
D. S. B.	5—14	·10	3·70	...	1·77	1	0·91	·021
	5—14	·05	4·50	...	1·54			
	6—14	·05	3·10	...				

TABLE No. I.—OBSERVATIONS ON CANALS—*concluded.*

Name of channel and reduced distance (R. D.) of discharge site.	Date of observation.	Slope ‰ S.	Depth D.	Gauge G.	Mean velocity V.	Ratio Depth / Width R.	Critical velocity ratio C. V. R.	Kutter's N.
LOWER CHENAB CANAL.—								
Jhang Branch, R. D. 65,000 ...	1—08	·12	8·10	8·55	3·05		0·965	·025
	2—08	·18	8·10	8·76	3 14		0·975	·024
	5—08	·22	7·53	8·60	3·15	·075	1·02	·026
	11—07	·18	7·40	8·62	3·40	to	1·12	·021
	12—07	·18	7·40	8·35	3·20	·165	1·06	·024
	3—08	·17	7·30	8·95	3·77		1·26	·018
	10—07	·18	7·20	8·48	3·63		1·22	·018
R.D. 218,000 ...	4—08	·17	8·64	8·77	2·72	1.0	0·82	·028
	4—08	·19	8·36	8·44	2·75	to	0·84	·029
	6—08	·16	7·26	8·65	2·74	·085	0·92	·027
R. D. 277,000 ...	4—08	·15	7·80	8·40	2·65	0 1	0·84	·025
LOWER JHELUM CANAL.—								
Northern Branch, R D. 307,200 ...	6—14	·20	4·40	...	2·37	·09	1·09	·021
	6—14	·20	4·30	...	2·05	to	0·96	·0235
	6—14	·18	3·80	...	1·92	·1	0·97	·023
	6—14	·20	3·70	...	1·90		0·97	·0235
Southern Branch ...	12—15	·10	4·22	...	2·79	·056	1·31	·013
KIRANA.—								
D. S. B.	5—14	·10	4·20	...	1·81	1	0·86	·018
	5—14	·10	3·70	...	1·77		0·91	·021
	5—14	·05	4·50	...	1·54		0·79	
	6—14	·05	3·10	...	1·25			

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APPENDIX.

In a paper entitled "The Transportation of Debris by Running Water" (United States Geological Survey, Professional Paper No. 86) Grove Karl Gilbert has recorded and discussed a number of observations on streams with discharges varying from one-tenth to one cusec, and transporting coarse sand.

These observations support the following conclusions:- That the quantity of silt or sand swept along the bed of a channel varies as a power of the velocity. When the velocity is high, or the silt relatively fine, it varies nearly as the square of the velocity, so that the expression $\frac{V^2}{D}$ is a measure of the bed load per cubic foot of water; or, so long as the relation $V=CD^{\frac{1}{2}}$ holds, the load per cubic foot is constant for different values of V and D.

In addition to the silt which is swept along the bed of a channel, silt is raised by eddies and carried forward in suspension. Obstructions on the bed of a channel cause sudden expansions of the stream, resulting in a change of momentum and consequent loss of energy in eddies. The quantity of silt in suspension will depend on the dimensions of these eddies with respect to the size of the grains of silt, and the dimensions of the eddies must depend, not only on the velocity, but also on the dimensions of the obstructions, that is on the rugosity. It is, therefore, possible that an increase of rugosity, although accompanied by a decrease of velocity, may enable a stream to carry the same total load as before, but with a greater proportion of the load in suspension. In channels with a silted or mobile bed the rugosity decreases as the velocity increases.

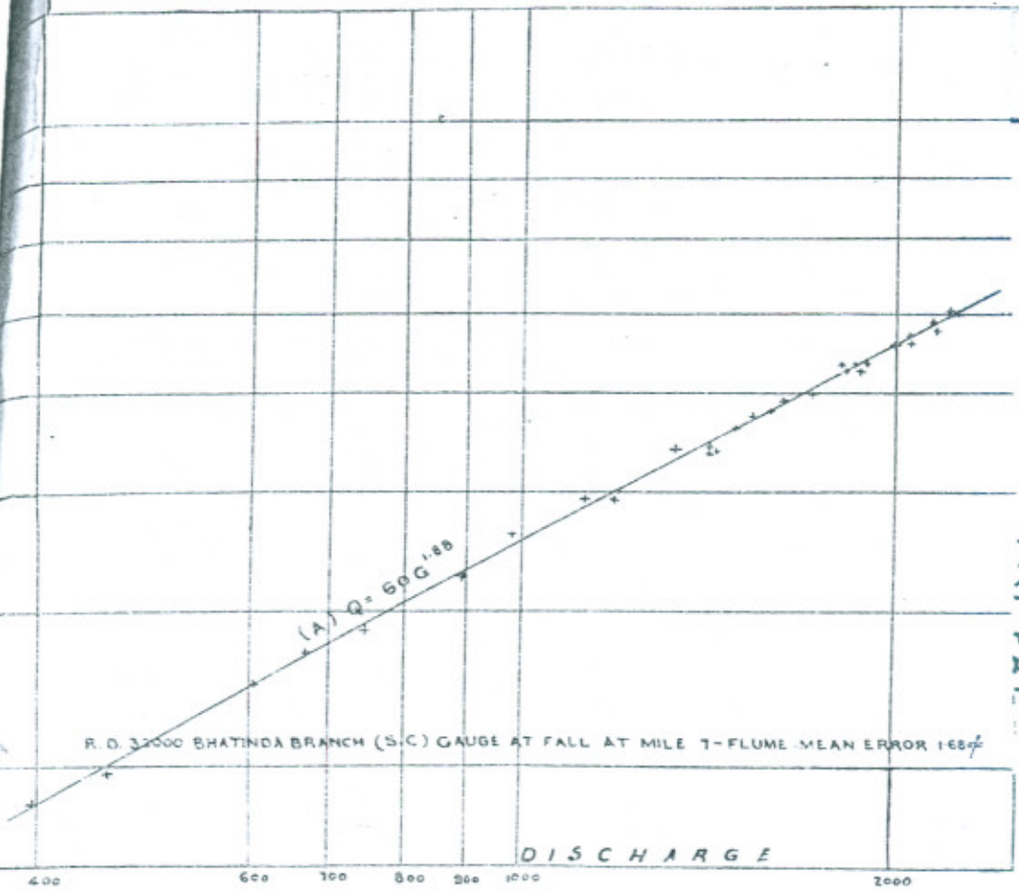
Silt waves form on the bed causing alternate expansion and contraction of the stream, and their dimensions are functions of the velocity and depth. When $V=\sqrt{gd}$ the waves disappear and the bed becomes smooth. When the velocity is greater than this critical velocity, waves of a different or opposite character are formed. In such channels, therefore, a decrease of velocity may not mean a decrease of transporting power.

OGARITHMIC DIAGRAM

YING RELATION BETWEEN GAUGE AND DISCHARGE
AT DIFFERENT DISCHARGE SITES

PLATE N:

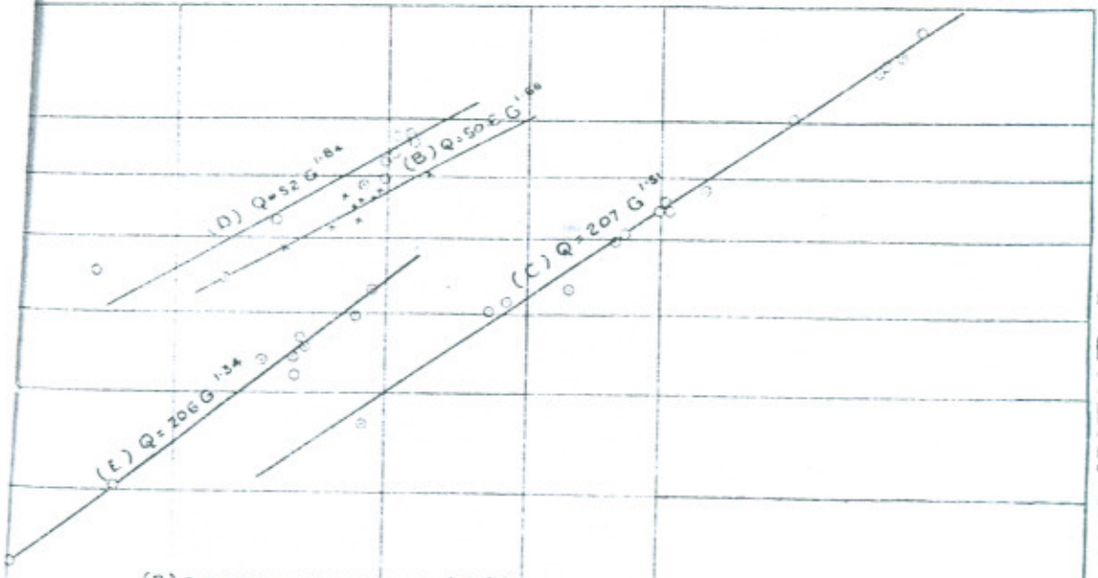
BHATINDA BRANCH
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LOGARITHMIC DIAGRAM

SHOWING RELATION BETWEEN GAUGE AND DISCHARGE
AT DIFFERENT DISCHARGE SITES

JHANG BRANCH



(B) R. D. 65000 JHANG BRANCH (L.C.C.) GAUGE AT FALL AT R. D. 9000 NO FLUME MEAN ERROR 2.4%

(C) R. D. 132000 MAIN LINE (S.C.) GAUGE AT DISCHARGE SITE FLUME MEAN VARIATION 2.3%

(D) R. D. 15000 PATIALA BRANCH (S.C.) GAUGE AT DISCHARGE SITE FLUME MEAN VARIATION 4.7%

(E) R. D. 1000 ABOHAR BRANCH (S.C.) GAUGE AT DISCHARGE SITE FLUME MEAN VARIATION 2.4%

POINTS INDICATED BY + REFER TO BHATINDA OR JHANG BRANCH

POINTS INDICATED BY ○ REFER TO MAIN LINE (S.C.) PATIALA AND ABOHAR BRANCHES

DISCHARGE

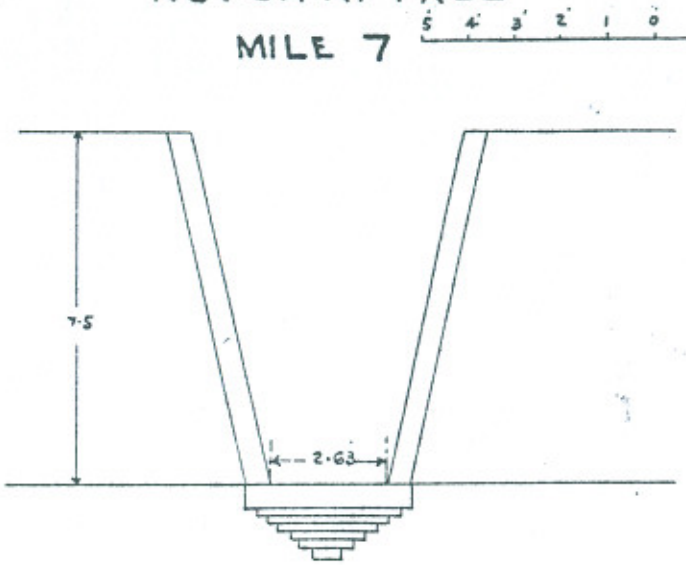
PLATE No. II

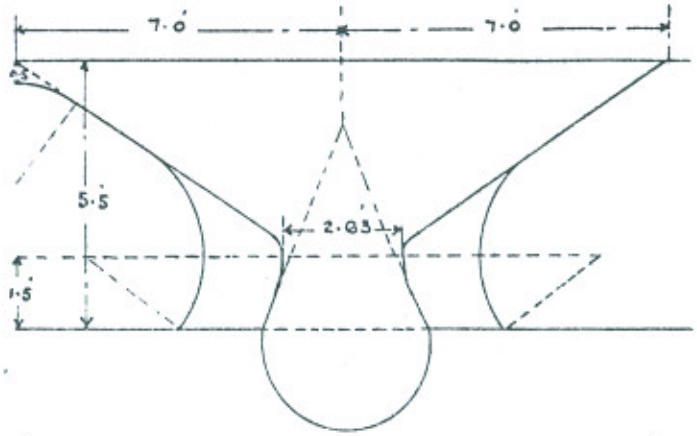
PLATE No. II

BHATINDA BRANCH

NOTCH AT FALL

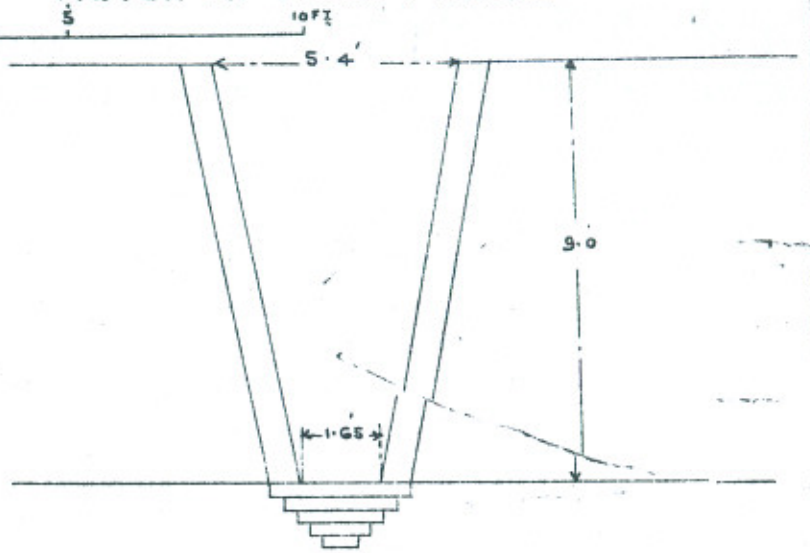
MILE 7

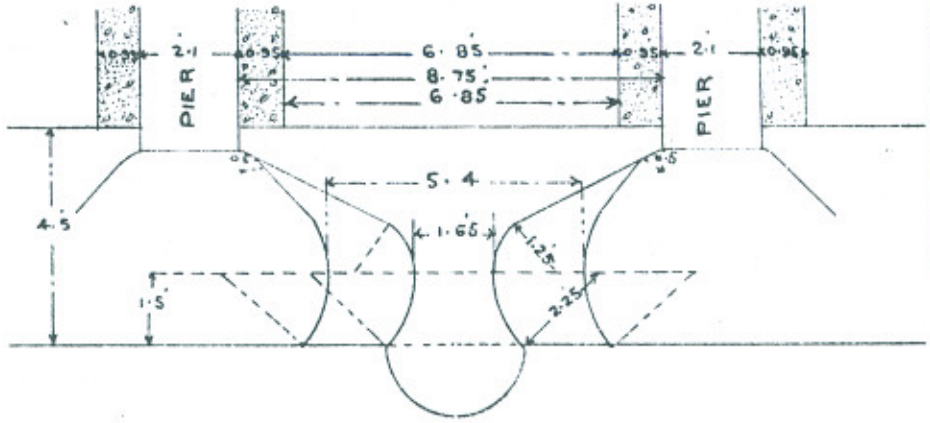




JHANG BRANCH

NOTCH AT FALL F. D. 69000





DISCUSSION.

MR. HARVEY, introducing his paper, remarked that his chief object in writing it was to advocate the adoption of a standard type of fall by means of which the discharge of a channel could be derived at once. Falls were used at present as gauge sites as far as possible, but in each case a discharge table had to be made by taking discharges of the channel near the fall.

The conclusions arrived at in the appendix were tentative. He had submitted evidence in support of these conclusions, but the committee had decided not to print it. The matter was one of considerable importance, and could with advantage be made the subject of special research.

MR. C. QUINN YOUNG remarked that he thought Mr. Harvey's paper tended to standardize work and suppress initiative. It was a recognised fact in irrigation practice that accurate discharges formed an important portion of revenue work, but the manner of observing these discharges should be left to the executive staff. The man responsible for a certain volume of water and a certain number of channels, knew the best method to apply to each, in order to observe and apportion its discharge. Minute and detailed standardized instructions were not necessary, otherwise confusion in applying such instructions to unsuited conditions might occur. Given the right executive they should be allowed to apply their own methods in observing discharges, and it was certain they would choose those suitable to the conditions. He did not wish to comment adversely on Mr. Harvey's paper as such, he only advocated that executive officers, with a life-long experience in observing discharges, should be allowed to follow their own methods.

MR. T. M. BOSTOCK supported Mr. Harvey in his desire for standard falls, and said that he would have found these very useful when he had recently to determine seepage losses from some distributaries in his charge.

RAI BAHADUR WAZIR CHAND CHOPRA pointed out that the idea of fixing gauging sites at falls where a permanent table could be framed was not a new one. It was ordinarily adopted when the falls were free and the weir a raised crest without notches. Gauging sites at notched falls, and more particularly at drowned falls, had not been much used, but the speaker had used a drowned fall as a gauging

site as early as 1905. This was the fall at Kot Khudayar on the Jhang branch of the Lower Chenab Canal. Previously the table had been based on a gauge downstream where there were great variations. The fall from water surface to water surface varied from 4·8 to 5·6 ft., while variations in the silt were also frequent, and the results were accordingly most unsatisfactory. He realised that the table should be based on the simultaneous readings of gauges upstream and downstream, and had made a careful series of observations of discharges downstream, noting the hydraulic conditions of the fall at each observation, so as to determine its actual coefficient for working depths. This was as high as 0·9, and compared very favourably with coefficients of 0·848 to 0·95 given on page 52 of Mr. Harvey's paper. The notches had been cement plastered in order to tighten them, and this was responsible for the high coefficient. His table was free from the evil consequences due to a rise of bed downstream, mentioned by Mr. Harvey. Seven or eight years after its introduction he learnt from the Executive Engineer, Lyallpur, that it was seldom out, and that the maximum error did not exceed two per cent. He did not understand the reason for the author's "additions of diverging walls downstream," and would appreciate enlightenment.

With regard to distributaries, he entirely agreed with Mr. Harvey's idea, and would go so far as to introduce a one foot fall in the head reach of every distributary for the purpose of discharge tables, provided sufficient head were available from the parent channel. The cost of raising the banks of a distributary by a foot or so would be a small sum to pay for accurate discharge tables on which all their distribution records were based. These tables should be based on upstream gauge readings if the falls were free under all conditions, otherwise on simultaneous readings of up and downstream gauges.

MR. C. A. COLYER said that he had found the paper extremely interesting. He wished to draw attention to sub-paragraph 4 on page 56, as he considered that there was a great deal of scientific interest in the problem of the critical velocity ratios.

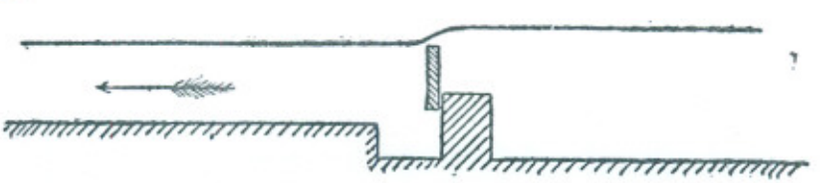
Mr. Harvey had studied the problem of silt transport and velocity ratio, and he would be glad to know if he could give the Congress some results of his study which would lead them further on this important subject. The chief interest to his mind was the simple statement that those critical velocity ratios and coefficients were inter-dependent variations, and he

hoped that at some future time Mr. Harvey might be able to give the Congress some further information about them.

MR. F. W. WOODS remarked that Mr. Harvey recognised only one method of regulating the water supply of a canal, *viz.*, by the control of the water level in the open channel as recorded on a vertical gauge ; and only two methods of measuring a discharge, *viz.*, by measurement of velocities and the cross sectional area of the current at a flume, or by reckoning the discharge by a formula based on the depth of the water upstream of a vertical trepezoidal-notched fall.

In the case of distributaries, that is of branch canals of less than 250 cusecs capacity, he was aware of only one existing method of computing the discharge, *viz.*, that reckoned from the depth of water in a flume. But these flumes were usually located too close to the head of a distributary, and he regarded their data as lacking in accuracy. He preferred to reckon the discharge at the first masonry fall on a distributary, even if it were at a considerable distance from the head, and even if this involved the inconvenience of reckoning separately the discharges of the (possibly several) irrigation outlets which might intervene between the head of the distributary and the first fall. As a matter of fact there was usually no difficulty in building a masonry flume within the first thousand feet length of a distributary and upstream of the first irrigation outlet. If this masonry flume were designed sufficiently narrow, or with its floor sufficiently high, to ensure a high velocity, so that the velocity through the flume would be great enough to prevent any deposit of silt on the floor, then the discharge of the distributary, for any given water level in the flume, would be constant, and reckonable from the water depth recorded over the floor at the centre of the flume.

Mr. Harvey seemed to have overlooked the possibility of controlling the water supply of a distributary or of a canal, and, at the same time, of measuring its discharge accurately by passing the water by a free overfall over a moveable gate-sill.



If the top of the moveable gate-sill were at the full supply level of the offtaking channel, or above that level, the overfall would be free, and if the water depth over the sill were a foot, the discharge would be about 3·3 cusecs per foot run of sill, or 33 cusecs over a gate-sill ten feet long. Eight such sills, or eight spans of ten feet, would suffice to pass the discharge of the largest distributary, and this result could generally be attained without difficulty, since it was usual to design such large distributaries with a margin of command of 1·5 feet or more.

The advantage of this method of the regulation of the supply was that it measured the discharge accurately, whilst controlling it, and at the same time helped to exclude the coarsest sandy silt from the offtaking channels, whose currents were usually less capable of transporting heavy silt than their parent channels.

Mr. Harvey might be interested to know that an instrument for measuring water surface slopes over so short a length of channel as a hundred feet had been manufactured, and was being experimented with on the Lower Jhelum Canal.

Referring to Mr. Harvey's remarks about the critical velocity ratio of the main line of the Sirhind Canal being lower than that in its branches, his attention was drawn to the data exhibited in the diagrams appended to Mr. Schönemann's paper on the design of distributary heads, which was presented to this Congress in 1916. These showed that the critical velocity ratio of an offtaking channel was usually greater than that of its parent channel at the point of offtake, the reason probably being that the offtaking channel was usually fed, under present practice, by a discharge under pressure through a submerged orifice under a descending gate. Discharge by a free fall over a gate-sill might make a considerable difference in this respect to the offtaking channel.

MR. E. S. LINDLEY said that making discharge observations and framing discharge tables was a subject on which he had worked, and claimed that his remarks would be rather supplementary to what Mr. Harvey had written than critical.

Mr. Harvey had not said much about errors in methods of observing, whereas he himself had found many more errors general, some of them due to departmental instructions, but members of the Congress had doubtless made the same discoveries and did not need elementary instruction. It was, however, worth record-

ing that observations properly made, with proper velocity rods, on a pitched flume free of silt, would agree with each other within one per cent. on large, and $2\frac{1}{2}$ per cent. on small channels.

For reducing observations to a table or curve, he had developed a method for which he claimed advantages. The method of drawing a curve by eye through a plot of the observations of a number of years he had rejected at once; the method of drawing a straight line through a logarithmic plot of fewer recent observations was seen to be wrong on applying it to a channel with considerable depth of silt on the gauge; while the same remark applied to the method of drawing a straight line of fixed slope through a logarithmic plot of a few full supply observations, though he had found several colleagues using this method with slopes corresponding to exponents all lying between 1·64 and 1·70.

By calculating a series of discharges for each of a set of typical trapezoidal channels, with $\frac{1}{2}$: 1 side-slopes, of different widths, gradients, and rugosities, by Kutter's formula, a value of $\frac{5}{3}$ was found the most suitable exponent and kept within permissible limits of error. The full formula was $D = k \times (g - s)^n$ where D was the discharge, g the gauge-reading, n the exponent $= \frac{5}{3}$, s the difference between gauge and depth, or the effective depth of the silt in the channel, and k a constant depending on width, slope, and rugosity. To fix the values of k and s for a channel, the most accurate method was to calculate them from reliable observations taken at full supply, and at the lowest supply run, while the silted bed was the same. Where it was impossible to run a low supply, $(g - s)$ could be observed direct, by sounding to an appropriate distance below the gauge site, but this would only be accurate in so far as the bed was even. Since ordinarily the most variable factor was the depth of the silt, k could be considered constant, and s the factor to be varied as the result of periodical observations, which need not be taken at several supplies as in fixing k at first.

To show what was here merely stated, and to give working directions in full detail, would pass the limits of what could be recorded in the discussion of another paper, but those who had worked on this method had found it practical and useful. Two reliable observations at different gauges sufficed to fix the curve accurately, while the method of adding a correction to the gauge, instead of working out a percentage to be added to the discharge, was simpler. A short table in a pocket-book giving for each discharge site the full supply discharge, the

value of k, and the present value of s, supplemented by a single table or a rough $\frac{5}{3}$ scale for a slide-rule, gave always at hand all the information of a full set of discharge tables for all sites. This led to the idea of a simple exponential formula for the discharges (not velocities) of channels, and this too was satisfactorily solved. Curiously, the day after it was solved brought a most favourable opportunity for using it. A letter from Mesopotamia asked for something to fill the place of Kennedy's diagrams, for very flat slopes and metric units, so as to save the great labour involved in calculating from the very brief tables of Buckley. It was not to be expected that anything would be available in India; months would have been needed either to communicate with Europe or to calculate and draw up a set of tables or diagrams: only this new formula made one diagram take the place of a set, and the calculation of three discharges sufficient to draw it. One day saw the diagram plotted and traced, and most of the time had been taken up in deciding the most useful range of variables to show, and planning the most effective use of the paper; the next mail took back a set of prints of this single diagram, in foolscap size; it was better than Kennedy's diagrams in that it read for any slope instead of only certain values, but the designing to critical velocities was rough, though not rougher than was unavoidable, when no data whatever had been supplied and had to be guessed.

The same formula had enabled him to make himself a slide-rule and a nomogram; the latter was only six by four inches, and could be read with as great accuracy as Kennedy's diagrams.

It was to be wished that Mr. Harvey had made more of his suggestion to avoid the labour and inaccuracy of periodical discharge observations, by calibrating works at which the discharge-gauge relation was independent of silt movements. At present little use was made even of free falls, and it was not realized that many falls were of such form as to discharge as if free, though drowned by as much as two-thirds, or that they require [illegible] if any modification to make them discharge free and a [illegible] formula. Mr. Harvey's suggestion of diverging [illegible] where little fall was available, meant, in the extreme, converting a fall into an enlarged open weir of his tail-cluster pattern. The best form for this and the minimum fall necessary for modularity were points on which information would have been welcome.

MR. A. S. MONTGOMERY, in closing the remarked that Mr. Quinn-Young had been amply answered by the evident and keen interest displayed in the accurate measurement of discharges. One or two members who had been prominent in discussion might suitably have contributed papers of their own.

Subsequent Contribution.

MR. BIHARI LAL UPPAL wrote that the author had mentioned some of the errors that were liable to creep in when making discharge observations, but in addition the following sources of error had also to be considered.

Firstly, In an earthen channel soundings were generally taken at certain distances apart, but in so doing it was possible that the exact profile of the bed and slope had not been obtained, that is to say, there might be an error in observing the area of the cross section.

Secondly, Error in selecting the lengths of the velocity rods to suit the depths. Generally rods of lengths slightly smaller than the depth of water at the section were selected for observing the velocity, but if a rod was not the correct length it would not give the actual velocity of the column of water moving in that section.

Thirdly, The effect of air currents. These greatly affected the velocity observations.

Fourthly, Observations of timings for the run fixed. The men who called out when the rods passed the beginning and the end of the run might fail to properly judge the exact moment when they passed.

Lastly, The observer holding the stop watch might fail to manipulate it exactly at the moments when the signals for the rods entering and leaving the run were given.

Mr. Harvey had collected some data of discharge observations on the Sirhind and Lower Chenab canals and had drawn some striking conclusions. The first was that the slope and the critical velocity ratio were not greater in the hot than in the cold weather, although there was a greater load of silt in the hot weather, but this had not been demonstrated, and it appeared that the author expected the slope and the critical velocity ratio to be greater in summer than in winter. It was reasonable to believe that the slope should be greater in summer, as with a heavier silt load, the silt would drop down in bigger quantities in the upper reaches, than in the

lower ; and examining the observations * for the main line of the Sirhind Canal it would be seen that the slope was actually greater in summer than in winter, so that the author's conclusion was not correct.

As for the critical velocity ratio the author expected it to be greater in summer, whereas actually it was not so, and indeed could not be so. The critical velocity ratio was given by V/Vo, where V was the mean velocity, and Vo the critical velocity for the depth obtaining in a channel. For ne gauge the discharge of a canal was less in the h ner than in the cold weather, hence in the relation $Q=$. Q were less in summer, V must also be less, as A was stant for the same gauge.

Strictly speaking the discharge measurement was nothing but the measurement of the momentum per second for the channel, after eliminating the consideration of the mass moved, that is $Q=MV$. For the same gauge, the momentum moved must be the same in summer as in winter. Since in summer the mass to be moved was greater, it was evident that V must be less, but according to Kennedy, Vo depended upon d only, so that it must be constant for the same gauge or depth, and therefore V/Vo, or the critical velocity ratio, must be less in summer than in winter. For this reason channels more usually silted in summer than in winter.

Unfortunately, the results of the summer and winter observations, which the author had compared, were not based on the same depth or discharge, and it would be interesting to have such data. He had prepared a statement from data of discharge observations of the Lower Jhelum Canal, which demonstrated that for the same gauge, the discharge in summer was less than that in winter, and from this it was clear that a smaller gauge in February would be sufficient to give the summer discharge. The mean of these results for each month had been plotted, and the diagram showed that, for the same discharge, the February gauge was smaller than the corresponding hot weather gauge. The February gauges were connected to give the discharge curve for the month, and from this curve the equivalent discharge in February was deduced as compared with the gauge occurring in the hot weather months. The results showed that for May the discharge was less by 13

* Page 58.

per cent., in June by 12 to 15 per cent., in July by 26 per cent., in August by about 31 per cent., and in September by about 28 per cent.

MR. HARVEY, in his reply, sympathized with Mr. Quinn-Young in his desire not to suppress initiative, but the measurement of water was not a case in which this was called for. It was a simple process, which could be automatic, and thus leave officers time to deal with the more complex questions which really called for initiative.

With reference to Mr. Colyer's remarks, he was not so satisfied with his theory of silt transportation as he was when he wrote the paper. It was the result of deductions made from other men's experiments and observations, and he felt that it required verification by experiments designed for the purpose, but this would have to be left for a research section, as the man on the canal had little time for experimental work.

He attributed the high coefficient obtained to the form of the fall, rather than to any particular method of pointing or plastering as suggested by Rai Bahadur Wazir Chand Chopra. The addition of gradually diverging walls downstream of the controlling section induced the formation of a standing wave at some distance beyond this section, and the exact position of the wave depending on the depth of water downstream of the fall, but the depth at the controlling section was not affected by the position of the wave, and therefore, the discharge was independent (within limits) of the water level downstream.

The flume suggested by Mr. Woods was practically what hor proposed when he added diverging walls to a fall, but ust always be some loss of head through such a flume; e, if the distributary downstream of the flume silted up, e wave, which formed in the flume, reached the con- tion, the discharge would, for the same depth at this e less than when the wave occurred at any point beyond ion. What the working head should be would depend liability of the channel to silting, but from six inches to would probably be sufficient in most cases. A rising designed by Mr. Woods, would be equally satisfactory neans of measuring the discharge, but it might not always desirable to take top water into a channel.

Mr. Lindley's method of obtaining quickly a discharge table for any site on a canal was interesting. His type of formula was practically the same as Manning's

$$V = \frac{1{\cdot}49}{n} M^{\cdot 67} S^{\cdot 5}$$

but he was inclined to think that Bazin's or Kutter's type of formula more nearly represented actual conditions in channels than any single termed exponential formula could do. Energy was lost in flowing water, through skin friction, and in eddies caused by changes of momentum, and each of these losses must be represented by separate terms in formulae for flow, since the first was independent of the depth, while the second depended on the relation between the size of the irregularities on the bed and sides to the depth. In calculating the resistances to motion of ships these losses were considered separately.

The first and second sources of error mentioned by Mr. Bihari Lal Uppal had been considered in the paper. The other sources also occurred, but he did not follow Mr. Uppal's remarks on momentum and critical velocity. His statement showed that the Lower Jhelum Canal silted at its head in the hot weather, but this happened in most canals, and might be the sole explanation of the fact that conditions farther down the canal appeared to remain much the same throughout the year. It had also been suggested that the greater viscosity of the water enabled it to carry more silt in the hot, than in the cold weather, on the same slopes. This might be so, but until more observations were available, not only of discharges, but also of slopes, to test hypotheses of this sort, it was unwise to draw conclusions.