For rabi data the absorption loss, as calculated by the formula, in Table V above, amounts to 17·5 per cent. of the canal head supply; which is very nearly the same figure as obtained for the kharif; but the figure shown by statistics is only 13·3 per cent This again, is due to the defective statistics of the years 1909-12; which put the average difference of rabi supply, between the canal head and distributary heads as only 370 cusecs, whereas the average shown for the preceding ten years had been 700 cusecs. Here also, our formula is evidently more reliable than the statistics. It is noteworthy that our statistics for recent years are markedly less reliable than those of the first decade of this century; possibly owing to a relaxation of the pressure and emphasis laid by Messrs. Beresford and Kennedy, when Chief Engineers, on the accurate statistical record of measurements of the discharge of canals and distributaries.

Absorption Losses, Lower Chenab Canal.

The following table is an abstract, by canal branches, of the hydraulic data of the Lower Chenab Canal :—

TABLE VI.

Name of Branch Canal.	Reach. From	Reach. To	Length (feet).	Average bed width (feet).	Average full water depth (feet).	Reduced absorption surface (millions of square feet).	Rate of absorption (column 6 × 1·33).	Loss by absorption (column 7 × column 8).
1	2	3	4	5	6	7	8	9
Main Line ..	0	40,000	40,000	260	11·6	11·08	14·77	163 7
Do.	40,000	200,000	160,000	...	...	...	...	...
...	...	...	200,000	...	10·94	48·32	14·58	704·3
Upper Gugera	...	...	282,000	...	9·6	35·10	12·77	448·3
Lower Gugera	...	...	388,000	...	6·8	25·91	9·0	233·6
Burala ...	...	...	229,000	...	6·14	14·27	8·19	116·8
Kot Nikka ...	...	...	91,000	...	3·9	2·80	5·18	14·5
Mian Ali ...	...	...	135,000	...	5·1	5·22	6·78	35·4
Rakh ...	...	...	278,000	...	6·94	12·83	9·25	118·7
Upper Jhang	...	...	308,000	...	8·55	32 39	11·4	369·3
Lower Jhang	...	...	189,000	..	6·56	9 13	8·75	79·9
Bhowana ..	...	...	37,000	...	5·8	1·20	7·75	9·3
Totals and averages		...	2,137,000	...	8·54	187·17	11·38	2,130·1

Our statistical records take no account of the discharge of the canal, or of its absorption losses, upstream of the gauging site at Chenawan, mile 8 (R. D. 40,000). Downstream of this site the absorption losses (column 9, Table VI) given by the formula are 2,130 — 164 = 1,966 cusecs.

The absorption losses calculated by our formula compare as follows with those indicated by the statistical records :—

TABLE VII.

Period.	Full capacity (cusecs).	KHARIF DATA. *According to Statistical Records.* Average supply (cusecs).	Ratio of column 3 to column 2.	Average loss by absorption (cusecs).	Percentage ratio of column 5 on column 3.	*Calculated by Formula.* Loss under full supply conditions.	Loss at average supply (column 7 × column 4).	Per cent. ratio of column 8 to column 3.
1	2	3	4	5	6	7	8	9
1899 – 1909 ...	10,730	8,721	0·81	1,480	17·0	1,966	1,592	18·3
1899—1912 ...	10,730	8,743	0·82	1,515	17·3	1,966	1,612	18·4
1903—1912 ...	10,730	8,957	0·84	1,482	16·5	1,966	1,651	18·4
1906—1912 ...	10,730	8,865	0·83	1,510	17·0	1,966	1,632	18·4
Averages ...	10,730	8,822	0.825	1,497	17·0	1,966	1,622	18·4
		RABI DATA. *According to Statistical Records.*				*Calculated by Formula.*		
1899—1909 ...	10,730	7,212	0·67	1,107	15·4	1,966	1,317	18·3
1899—1912 ...	10,730	7,419	0·69	1,216	16·4	1,966	1,357	18·3
1903—1912 ...	10,730	7,723	0·72	1,251	16·2	1,966	1,416	18·3
1906—1912 ...	10,730	7,582	0·71	1,343	17·7	1,966	1,396	18·4
Averages ...	10,730	7,484	0·70	1,229	16·4	1,966	1,371	18·3

The aggregate kharif loss indicated by our statistics amounts to 17 per cent. of the average canal head supply, as compared with 18·4 per cent. calculated by the formula ; and the aggregate rabi loss indicated by our statistics amounts to 16·4 per cent. of the average canal head supply, as compared with 18·3 per cent. calculated by the formula.

General comparison of Statistics with Formula.

The hydraulic data, bearing on the subject of absorption losses, of the three great canals discussed above, may be abstracted and compared *inter se*, as follows :—

TABLE VIII.

Name of Canal.	Canal mileage (miles of 5,000 feet).	Full capacity (c.secs).	Average full water depth (feet).	Reduced absorption surface at full supply (millions of square feet).	Loss at full supply by formula (c.secs).	KHARIF DATA. Average supply (cusecs).	Ratio of average to full supply.	Percentage lost. By Statistics.	Percentage lost. By Formula.
1	2	3	4	5	6	7	8	9	10
Upper Bari Doab	339·8	6,500	7·0	122·8	1,150	5,046	0·775	17·7	17·7
Sirhind ...	455·8	8,000	7·9	133·7	1,410	5,175	0·650	17·0	17·7
Lower Chenab ...	419·4	10,730	8·4	176·1	1,966	8,822	0·825	17 0	18 4
Averages ...	405	8,410	7·8	144	1,509	6,348	0·75	17·23	17·93
						RABI DATA.			
Upper Bari Doab	339·8	6,500	7·0	122·8	1,150	2,666	0·41	19·0	17·7
Sirhind ...	455·8	8,000	7·9	133·7	1,410	4,545	0·57	13·3	17·5
Lower Chenab ...	419·4	10,730	8·4	176·1	1,966	7,484	0·70	16·4	18·3
Averages ...	...	...	...	...	...	4,898	0·56	16·23	17·83

These figures do not take account of the first twenty-six miles of the Sirhind Canal, or of the first eight miles of the Lower Chenab Canal, above their gauging sites. If these upper reaches be reckoned in, we have :—

TABLE IX.

	Sirhind.	Lower Chenab.
Canal mileage	481·8	427·4
Average full water depth	8·55	8·54
Reduced absorption surface at full supply	161·9	187·2
Absorption loss at full supply	1,844	2,130

In the light of these figures the formula suggested in this paper is offered to the profession with some confidence, as regards canals discharging over 500 cusecs. The value of $c = 1{\cdot}33$, applied to the "reduced wetted surface" of a channel gives about the same results as $c = 1{\cdot}2$, applied to the whole wetted surface, or wetted perimeter.

This paper opened with an extract from a demi-official letter from Colonel Dyas to Colonel Crofton in 1863 ; and it may well close with a further extract from the same letter, which has a certain human interest. We are accustomed to think that the pioneers of hydraulic science in this country had a freer hand, and a wider discretion in research, than we have now ; but we see from this letter that the energetic scientist had his troubles then, as always has been the case. We find Dyas writing :—

"I wish they would give me what I applied for, a man to make experiments and observations. The executive engineers and their assistants are so bullied with accounts and paper work now-a-days, that they can absolutely do nothing I want. Fulton actually applied to me officially to be allowed to chuck up all Punsal Registers ! ! ! because he had no one to copy them out in the lithographed forms. Could you pitch in to him strong and steady when you him ? You may be listened to when I am not. They look on me as a *yagee* beast, and I think I have had some more

curious than pleasant correspondence with Maclagan lately. I declare that your friendship for me is one of the few comforts in life that I have. I am growing to detest my work which I used to be so fond of, and to hate my very existence in this country".

There have been Dyases and Fultons in every age and every country;—men who think, and men who don't; and the latter are always happier in their life. Doubtless the College of Cardinals regarded Galileo as a *yagee* beast when he asserted that this Earth was spherical, not flat.

APPENDIX A.

Lengths, wetted areas, and full water depths of the Upper Bari Doab Canal and its branches.

Reduced Distances		Length (feet).	Bed Width (feet).	Full Water Depth (feet).	Reduced Wetted Perimeter (feet).	Reduced absorption surface (millions of square feet) (col. 3 × col. 6).	Rate of absorption loss (col. 5 × 1·33).	Loss by absorption (col. 8 × col. 7).
From	To							
1	2	3	4	5	6	7	8	9
	Main Line (Discharge 6,500, side slopes 1 to 1).							
0	14	14,000	120	6·0	129	1·80	8·0	14·4
14	34	20,000	116	6·0	125	2·50	8·0	20·0
34	40	6,000	120·5	6·0	129	0·77	8·0	6·2
40	54	14,000	117	6·0	126	1·76	8·0	14·1
54	60	6,000	118	7·0	128	0·77	9·33	7·2
64	67	3,000	135	7·0	145	0·44	9·33	4·0
67	77	10,000	140	10·0	154	1·54	13 3	20·5
77	92	15,000	145	10·7	160	2·40	14·3	34·3
92	114	22,000	155	9·4	178	3·92	9·87	38·7
114	123	9,000	165	10·0	179	1·61	13·3	21·4
123	151	28,000	165	10·5	180	5·04	14·0	70 6
Totals and averages		151,000	137	8·36	149	22·55	11·15	251·4
	Salampur Feeder (Side slopes 1 to 2).							
0	4	4,000	64	5·14	69	0·28	6·85	1·9
4	6	2,000	58	5·5	64	0·38	7·33	2·8
6	9	3,000	52	6·7	59	0·18	8·93	1·5
9	14	5,000	50	6·7	57	0·29	8·93	2·5
14	28	14,000	76	5·4	82	1·15	7·2	8·3
28	30	2,000	72	6·2	78	0·16	8 27	1·3
30	34	4,000	78	5·7	84	0·34	7·6	2 6
34	38	4,000	64	5·0	69	0·28	6·67	1·9
Totals and averages		38,000	74	5·56	80·5	3·06	7·45	22·8
Carried over ...		189,000	...	...	...	25·61	...	274·2

APPENDIX A—*contd.*

Reduced Distances		Length (feet).	Bed Width (feet).	Full Water Depth (feet).	Reduced Wetted Perimeter (feet).	Reduced absorption surface (millions of square feet) (col. 3 × col. 6).	Rate of absorption loss (col. 5 × 1·33).	Loss by absorption (col. 8 × col. 7).
From	To							
1	2	3	4	5	6	7	8	9
Brought forward		189,000	...	...	...	25 61	...	274·2
		Farid Nagar Feeder (Side slopes 1 to 2).						
0	5	5,000	65	5	70	0·35	6·67	2·3
5	8	3,000	72	3·7	76	0·23	4·93	1·1
8	10	2,000	75	5·7	81	0·16	7·6	1 2
10	18	8,000	78·5	5·8	65	0·52	7·73	4·0
18	19	1,000	84	6·75	91	0 09	9·0	0·8
19	22	3,000	70	6·1	76	0·23	8·13	1·9
22	35	13,000	68	4·6	73	0·95	6·13	5·8
35	38	3,000	66	4·85	71	0 21	6 47	1·4
38	41	3,000	82	4·66	87	0·26	6·21	1·6
Totals and averages		41,000	67	5·0	73	3·00	6·7	20·1
		Kasur Branch Upper (Side slopes 1 to 2).						
0	20	20,000	85	6 5	92	1 84	8·67	16·0
20	37	17,000	85	6·7	92	1·56	8·93	13·9
Totals and averages		37,000	85	6·58	92	3 40	8·8	29·9
		Kasur Branch Lower (Side slopes 1 to 2 ,						
0	30	30,000	55	5	60	1·80	6·67	12·0
30	46	16 000	53	5·2	58	0 93	6 93	6·4
46	65	19,000	52	5·2	57	1 08	6·93	7 5
65	108	43,000	52	5·1	57	2·45	6 8	16 7
108	134	26,000	43	6	49	1 27	8·0	10·2
134	168	34,000	39	6 7	46	1 56	8·93	13·9
168	196	28,000	34	6·4	41	1·15	8·53	10·2
196	230	34 000	33	6	39	1·33	8 0	10·6
230	274	44,000	20	5 3	27	1·19	7·07	8·4
274	306	32,000	16	5·5	22	0·70	7·33	5 1
Totals and averages		306,000	38	5·6	44	13·46	7·5	101·0
Carried over ...		573,000	...	...	...	45·47	...	425·2

APPENDIX—*contd.*

Reduced Distances		Length (feet).	Bed Width (feet).	Full Water Depth (feet).	Reduced Wetted Perimeter (feet).	Reduced absorption surface (millions of square feet) (Col. 3 × col. 6).	Rate of absorption loss (Col. 5 × 1·33).	Loss by absorption. (Col. 8 × col. 7).
From	To							
1	2	3	4	5	6	7	8	9
Brought forward		573,000	...	...	...	45·47	...	425·2
		Main Branch Upper (Side slopes 1 to 1).						
0	10	10,000	112	10	126	1·26	13·3	16·8
10	25	15,000	100	10·2	114	1·71	13·6	23·3
25	42	17,000	106	8·8	118	2·01	11·73	23·6
42	62	20,000	112	9·9	126	2·52	13·2	33·3
62	79	17,000	100	11·1	116	1·97	14·8	29·2
79	124	45,000	106	9·8	120	5·40	13·07	70·6
Totals and averages		124,000	...	9·9	...	14·87	13·2	196·8
		Main Branch Lower (Side slopes 1 to 2).						
0	75	75,000	100	7·6	108	8·10	10·13	82 0
75	115	40,000	90	7·8	98	3·92	10·4	40·8
115	150	35,000	90	7·5	98	3·43	10·0	34·3
150	170	20,000	86	7·5	94	1·88	10·0	18·8
170	189	19,000	81	7·7	89	1·69	10·27	17·4
189	271	82,000	74	6·9	81	6·64	9·2	61·1
271	304	33,000	72	5·8	78	2·57	7·73	19·9
304	375	71,000	63	5·65	69	4·90	7·53	36·9
375	432	57,000	54	5·0	59	3·36	6·67	22·4
432	446	14,000	53	5·0	58	0·81	6·67	5·4
446	452	6,000	32	5·0	37	0·22	6·67	1·5
452	460	8,000	31	4·8	36	0·29	6 4	1·9
Totals and averages		460,000	...	6·8	...	37·81	9·06	342·4
Carried over	...	1,157,000	...	...	...	98·15	...	964·4

APPENDIX A—*contd.*

Reduced Distances		Length (feet).	Bed Width (feet).	Full Water Depth (feet).	Reduced Wetted Perimeter (feet).	Reduced absorption surface (millions of square feet) (Col. 3 × col. 6).	Rate of absorption loss (Col. 5 × 1·33)	Loss by absorption (Col. 8 × col. 7).
From	To							
1	2	3	4	5	6	7	8	9
Brought forward		1,157,000	...	...	...	98·15	...	964·4
		Lahore Branch (Side slopes 1 to 2).						
0	49	49,000	60	6·3	66	3·23	8·4	27·1
49	96	47,000	58	6·2	64	3·01	8·27	24·9
96	133	37,000	56	5·8	62	2·29	7·73	17·7
133	144	11,000	53	5·4	58	0·64	7·2	4·6
144	173	29,000	52	5·5	58	1·68	7·33	12·3
173	200	27,000	46	5·0	51	1·38	6·67	9·2
200	218	18,000	45	5·0	50	0·90	6·67	6·0
218	257	39,000	40	4·2	44	1·72	5·6	9·6
257	284	27,000	36	4·0	40	1·08	5 33	5·8
Totals and averages		284,000	...	5·5	...	15·93	7 36	117·2
		Sobraon Branch (Side slopes 1 to 2).						
0	39	39,000	40	6·5	47	1·83	8·67	15·9
39	55	16,000	37	6·3	43	0·69	8·4	5·8
55	95	40,000	35	6·4	41	1·64	8·53	14·0
95	155	60,000	32	5·7	38	2·28	7·6	17·3
155	204	49,000	20	5·0	25	1·23	6·67	8·2
204	252	48,000	15	4·8	20	0·96	6·4	6·1
252	258	6,000	13	3·7	17	0·10	4·93	0·5
Totals and averages		258,000	...	5·8	...	8·73	7·77	67·8
Grand totals and averages ...		1,699,000	64	7·0	72	122·81	9·36	1,149·4

DISCUSSION.

MR HADOW, in opening the discussion, remarked that Mr. Woods' formula for absorption contained the following factors—the reduced area of the wetted surface, the depth of water, and a coefficient which was said to vary with the capacity of the channel, and to take into account any variation in the temperature of the water due to the size of the channel.

The factor of "the distance travelled through the soil" * was expressly omitted and no reference was made to the effect that the level of the subsoil water table might have on absorption, although the Amritsar experiment† was made with the bed only $2\frac{1}{2}''$ above the subsoil water table—a condition which was not typical of canals as a whole. They were asked to believe, therefore, that the level of the subsoil water table had no effect on absorption, and that the absorption in any given channel was the same whether the level of the subsoil water table was above or below the bed. In most canals the level was above the bed level in the head reaches and very much below it towards the tail, and it would seem that a formula could not be complete for general application which did not take into account the level of the subsoil water table, since when this level was above the bed, the head was not that due to the depth of water in the channel only.

Mr. Woods had rejected the factor of the 'distance travelled through the soil,' because once the water passed the wetted perimeter it was lost for irrigation. This was true, but all the same a very real interest was attacheds to what happened to this water even if their knowledge did not come up to their interest. The rate of absorption was governed by the rate at which the water that had passed the wetted perimeter could flow away, and this in turn was not only governed by the head due to the depth of the water in the channel, but also by the "head" at any particular point and 'the distance travelled through the soil.' It did not seem sufficient to say that because the water was lost no further interest need be taken in it from the absorption point of view ; the rate of absorption, which was governed by the rate the water already absorbed could continue to pass into the soil, seemed to the speaker to depend to some extent on a head of water pressure, which was not the depth of water in the channel, but some other depth, and on the distance travelled through the soil.

* Page 13.
† Page 16.

MR. A. S. GIBB said that it had been shown in the first part of the paper, that direct experiment and the views of experts agreed that, for parallel flow through soil or sand, the discharge varied directly as the head and inversely as the distance travelled through the saturated medium. The actual discharge through a capillary tube worked out rationally from first principles was* :—

$$Q = \frac{P \pi R^4}{8 \eta l}$$

where P was the head, R the radius of the tube, η the coefficient of viscosity, and l the length of the tube ; but having established these principles, the author proceeded to ignore them. Having accepted the fact that the rate of percolation varied inversely as l, this factor could not be ignored. Further, to assume that the head was "the depth of water in the canal" was equivalent to saying that, if a high level tank were connected to a low level reservoir by a pipe, the head would be equal to the depth of water in the upper tank, whereas in this case it was the vertical distance between the water surfaces of the two tanks.

Imagining that percolation from a canal took place through vertical capillary tubes from the canal bed down to the ordinary spring water level, and neglecting for the moment the capillary attraction of the surrounding soil, then if h were the vertical distance from the water surface in the canal to the spring water table, and l the distance from the canal bed to the under ground water table, other things being constant, the rate of flow would be equal to $K \times \frac{h}{l}$ where K was a constant. But $h = l + d$ when d was the depth of the canal, and hence the rate of flow $= K \times \frac{l+d}{l} = K\,(1 + \frac{d}{l})$. Where d was small compared to l, the flow would be nearly constant and almost independent of the depth of the canal.

In reality, however, the problem was not so simple. Capillary action tended to draw the water away from the region of saturation and to spread the moisture in all directions through the soil, so that when the spring water level was a long way down, there came a point on each stream tube when the soil ceased to be fully saturated. This was evidently the point of virtual outflow, since it was here that the percolating stream

* "General I hysics for Students" Edwin Edser, pages 493-4.

reached atmospheric pressure, consequently the head h in any stream tube would be the vertical distance of travel, and l would be the distance along the tube of flow from canal bed or side to this point. The solution of the percolation problem thus involved the determination of the distance from the canal bed and sides at which the soil ceased to be saturated. When the canal was large and the spring level not far below its bed, there might be saturation of some portion of the soil all the way down and this would have to be treated as a special, though important case.

Whatever the complete general expression for the loss by percolation might be, it must express a balance between a propelling force or head and a resistance. It would therefore certainly involve a head h, which for any tube of flow would be the distance from the water surface in the canal to some point in the soil under or surrounding the channel. It would also necessarily involve the resistance, expressed as the distance measured along the tube of flow from the canal bed or side to the same point in the soil, but the author's formula contained neither of these. In their place the depth of the canal was erroneously considered as the head and, by omitting to take any account of the distance the percolating water must travel, failed to give expression to any forces of resistance opposing the head.

As was usually done in such cases the author had recourse to a coefficient, but when a coefficient was not constant, it was necessary to give some reason for its variation, and this was supplied in the form of a remark* which appeared to mean that the author assumed that the temperature of the water in canal channels varied inversely as some function of the hydraulic mean depth. The difference of temperature was the only reason given for the difference between the values of the coefficients for large and for small channels, which were given in Table II of the paper†. For a 10,000 cusec canal $C = 1{\cdot}16$, and for a one cusec watercourse $C = 5{\cdot}6$, so that the coefficient for the main line of a canal was nearly five times what it was for a watercourse, and this was attributed to the difference in the temperature of the water.

From the formula for the flow through capillary tubes already quoted it was evident that the discharge varied inversely as the coefficient of viscosity, which depended on the temperature in the way expressed in the following empirical formula estab-

* Page 19.
† Page 19.

lished by Thorpe and Rodger as the result of certain experiments *

$$\eta = \frac{0{\cdot}017944}{(1+0{\cdot}023121t)^{1{\cdot}5423}}$$

where t was the temperature in degrees centigrade *.

Applying this to the case of the 10,000 cusecs main line canal and the one cusec watercourse, the difference in temperature should cause the discharges through the soil to be as 1 : 5, that is the coefficients of viscosity were as 5 : 1, so that if the temperature in the main canal were zero, then η would equal ·018, and in the watercourse $\frac{·018}{5} = ·0036$, which corresponded to a temperature of approximately 82° C (about 180° F). Similarly, if the main line temperature were 15° C (about 58° F) then the water in the watercourse would be over 100° C, that is, it would be boiling. If 5° C be taken as a possible difference of temperature between a large and a small channel, then the coefficients of viscosity for water, say at 15° and 20° C, would be ·0112 and ·0100 respectivly, and the loss, other things being equal, would be in the ratio of $\frac{112}{100}$, that is the loss from the hotter channel would be twelve per cent more than from the other channel. He therefore considered that column 9 of Table II of the paper could not be accepted.

There were two ways of carrying out an investigation of this kind. The first was the rational method, which, starting from universally accepted first principles, arrived at its object by a process of pure reasoning, mathematical or otherwise, and assumed only the principle of cause and effect. The other was the empirical method, which, confessing ignorance of the principles involved, sought to arrive at a working formula by an analysis of a large number of detailed practical observations. In this case the result was based on the observed data, and consequently these observations could not justly be criticised when they diverged from the resulting formula.

The author, however, had applied neither of these methods, but one that involved guessing values for a coefficient which varied by five hundred per cent. This could not be called rational, and since the irrigation statistics were questioned when they differed from the results, the empirical method had evidently not been employed. The method used not being scientific was not likely to lead to useful results.

* " General Physics for Students " Edwin Edser, page 500.

MR. LINDLEY in drawing attention to the five variable factors that affected the problem* pointed out that variations of temperature beyond the variation depending on the size of the channel, which was covered by a variable coefficient, had been neglected and while this might be done in testing the formula by statistics of whole years or in applying it to obtain mean results, in dealing with single observations, especially those made on still water, to neglect it was inconsistent with the precision that the formula appeared to attempt. Though the Hansi Canal experiments were mentioned as showing the great variation of porosity of the same soil in the same place, equal mean porosity had been assumed at the heads and the tails of the Panjab doabs because no such variation had been proved ; but since the loss in an observation was as much as ten per cent. of the observed discharge, and there were few recorded observations of tails, such lack of proof was only to be expected. The distance which percolation had to traverse the soil was neglected, and no mention was made of the level of the subsoil water ; while it was remarked that after the water has once passed the perimeter of the channel, it was lost, and was therefore of no further concern.

For any given set of conditions, perimeter, depth of channel, and porosity of soil, there would be a certain depth of subsoil water surface below the bed which would allow of free percolation ; and while any further lowering of the water table would not increase the percolation from the channel, any raising would begin to choke the discharge, until the water-table rose above the water-level in the channel when infiltration and not percolation would take place. On the strength of the agreement of certain authorities that flow through a medium varied with the hydraulic gradient, it was asserted that the percolation varied with the head on one side of the surface and was at first taken to vary proportionately to it. This latter assumption was, however, abandoned when the coefficient was found to vary, while the former neglected the fact that the length of the percolation path, in which head was consumed, would also vary with the head and with any increase of flow.

The formula at present used to calculate absorption could be expressed in the form $k \times a$, where a was the wetted area, and k a coefficient generally taken as eight cusecs per million square feet. The formula proposed by the author was $c \times \acute{a} \times d$ where c was a new coefficient, $\acute{a}$ the wetted area

* Page 13.

(reduced to allow for a lower rate of absorption in parts not so far below the surface,) and d the central depth of water in the channel. No explanation had been given of how the coefficient c was arrived at; apparently a multiplier had been arbitrarily chosen, which would give a satisfactory coefficient when divided by the hydraulic mean depth R, and then divided by R to give it. In fact the multiplier and c were arbitrary coefficients, which could be modified if they were found not to agree with the data. Any reduction of the wetted area called for the calculation of a new figure for each channel, and though the result would be accurate for trapezoidal channels if c were constant, as this was not the case, the full wetted area could be taken without loss of accuracy, instead of the depth, and the coefficient modified if necessary.

Substituting $a \times R$ for the author's $a' \times d$ and $M \div R$ for c, and simultaneously modifying M to M', the formula became $\frac{M'}{R} \times a \times R$ which simplified to $M' \times a$.

The last was again the present formula with an arbitrary and variable coefficient substituted for an arbitrary constant, and it only remained to see which of the two was more nearly in agreement with the facts.

The author had, as a first step, in devising his formula, made the absorption rate proportionate to the depth, and had then entered a coefficient inversely proportional to the hydraulic mean depth, while the multiplier from which this coefficient was derived was not constant, but varied in some undefined manner with the size of the channel. In calculating the data of channels to test the results of his formula by facts, the author had however reverted to the constant coefficient, and had taken the absorption as directly proportional to the discharge and not to the depth, that is actually to the $\frac{5}{3}$ power of the depth (approximately and very nearly). This last assumption was not justified when applied to observations on channels, but in the case of statistics was untrue only to the extent to which channels were not run at full supply or closed down. It was also observed that the coefficient, deduced for the Amritsar tank observations, was applied not for the depth used in the tank, but for that of an equivalent channel of the same hydraulic mean depth as the tank.

MR. NICHOLSON said he had not been able to fathom Table II.* Its basis seemed to be the fact that the ratio $\frac{b}{d}$ was a constant function of the discharge, as delineated by the smooth

* Page 19.

curve on the author's diagram. He had however prepared a diagram giving the actual values of $\frac{b}{d}$ plotted against discharges for all the channels, of which he could obtain data, on four of the major canals of the province, and the result shewed that there was no such constant relation as apparently had been assumed by the author, so that there seemed to be something wrong at the very outset. Further, analysing Table II, it was evident that column 9 was the product of columns 7 and 8 ; while C was doubtless (from the diagram) a function of the discharge, but he had been unable to find out how the multiplier in column 8 had been obtained. Seeing that Table II gave such regular curves for the relations plotted by the author, he had himself plotted various other relations from the table, of which the most interesting was the values of $Q = c\,a\,d$ plotted against the depth of water in the channel. From the initial assumption of the author that the percolation flow was proportionate to the area of the wetted surface and to the mean head of water pressure against it * $Q = c\,a\,d$ plotted against the depth should give a smooth curve. The result, however, was otherwise, shewing that the constants in the formula established by the author, when actually applied, gave results contrary to his fundamental principles.

Further, in working out the absorption in Tables IV to VIII and Appendix A the auther had not taken any account of this varying value of the constant c, as given in Table II, to suit the different conditions, but assumed $c = 1{\cdot}33$ and $Q = 1{\cdot}33d$ for all channels. This, having been plotted on the accompanying diagram for comparison with $Q = c\,a\,d$ evaluated from the author's coefficients, shewed the great difference between the results obtained from the author's varying coefficients and from the constant coefficient of 1·33 which he also used.

The fact that the rate of percolation could be taken as approximately $Q = c\,d$ had been accepted for some time. Mr. Carne some years previously had put it forward at the Congress and it appeared, where spring level was near canal bed, that such a relation was supported by both theory and experiment.

In the winter of 1914 when the speaker was Sub-Divisional Officer at Rupar, he had carried out a series of observations to determine the absorption losses on the main line of the Sirhind Canal while the conditions were very favourable as only one branch was carrying the whole supply. Observations were made three times daily at each site, for three days, by

* Page 15.

carefully trained observers, of whom three were officers. The results obtained were :—

	Mean depth.	Rate of loss per million square feet.
Head reach	... 6·5 feet	5·3
Tail reach	... 8·3 feet	8·8

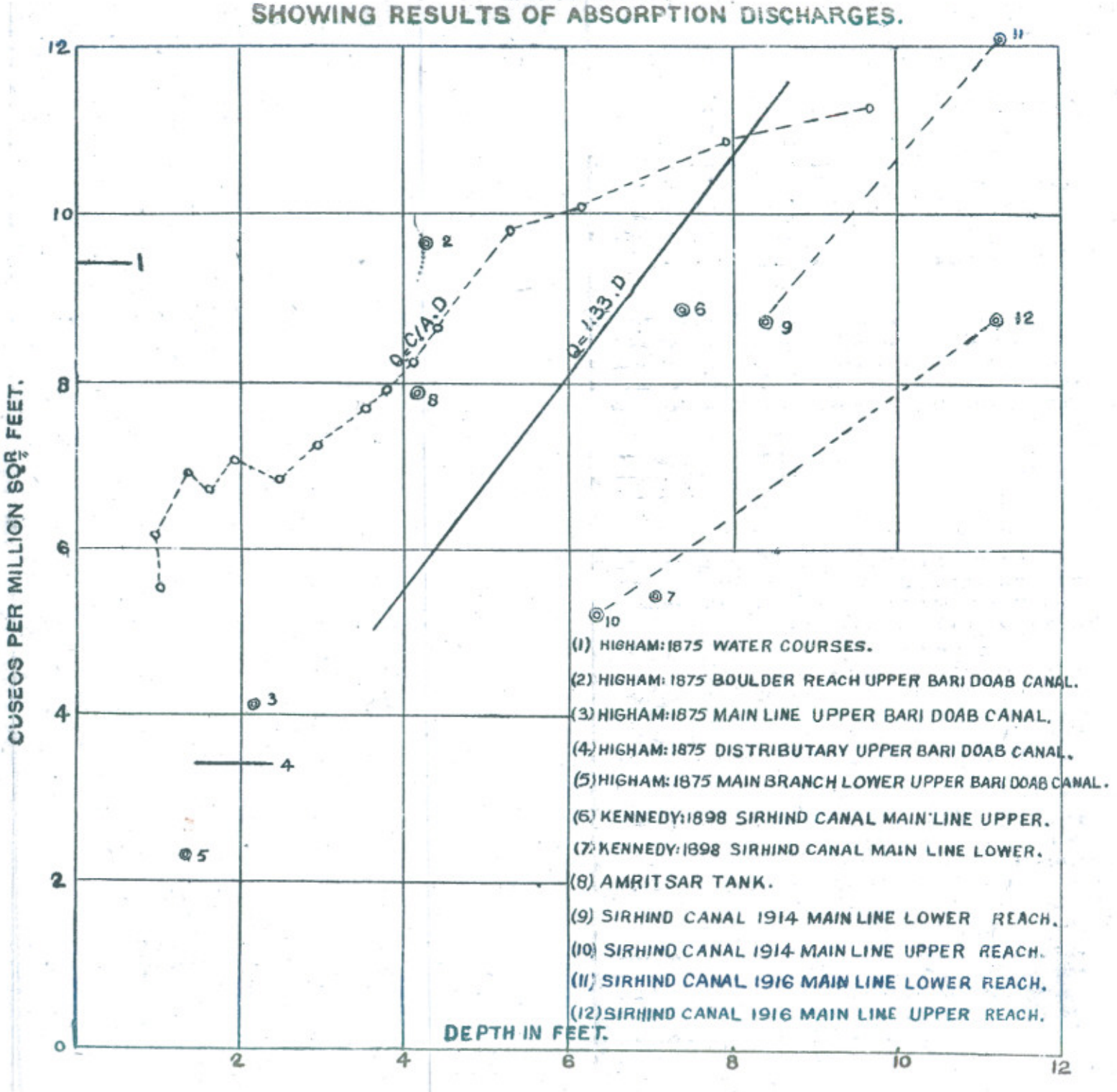
Continuous discharges were again observed in 1916, three times a day, for three days, at the head of the canal and at the discharge flumes at the heads of each of the branches, twelve officers being available for the purpose. The results obtained were those of eighty-eight discharge observations and were as follows :—

	Mean gauge.	Loss per million square feet.
Main line head reach	... 11·2 feet	8·7
Main line tail reach	... 11·3 feet	12·1

These results, together with the 1914 ones, have been plotted on the diagram and indicate that the rate of absorption is proportional to the depth in each reach, but indicate a very different rate of loss in the two reaches.

The author had given Mr. Higham's figures for absorption, but stated he had no information regarding the depths running at the time. The whole report of these experiments had, however, been printed and circulated as Joint Secretary's Circular No. 37-1010-I, dated Lahore, 4th March 1876, and from this original report the figures had been obtained and plotted on his diagram. It was interesting to observe that Mr. Higham's results for the lower main branch of the Upper Bari Doab Canal shewed a rate of absorption proportional to the depth. The values given by Mr. Higham for branches appeared low, but this was due to the fact that very low supplies were running in the branches when the experiments were made.

The author had postulated the fact that a difference of soil made little or no difference in the rate of absorption, but this was not in accordance with generally accepted theories or experience, and it seemed that the high rate of absorption in proportion to the depth obtained on the main line of the Upper Bari Doab Canal was due simply and solely to the fact that the canal there was in a boulder or shingle stratum. The


SHOWING RESULTS OF ABSORPTION DISCHARGES.
CUSECS PER MILLION SQ. FEET.
DEPTH IN FEET.
0
2
4
6
8
10
12
Q=C√A.D
Q=1.33.D
(1) HIGHAM: 1875 WATER COURSES.
(2) HIGHAM: 1875 BOULDER REACH UPPER BARI DOAB CANAL.
(3) HIGHAM: 1875 MAIN LINE UPPER BARI DOAB CANAL.
(4) HIGHAM: 1875 DISTRIBUTARY UPPER BARI DOAB CANAL.
(5) HIGHAM: 1875 MAIN BRANCH LOWER UPPER BARI DOAB CANAL.
(6) KENNEDY: 1898 SIRHIND CANAL MAIN LINE UPPER.
(7) KENNEDY: 1898 SIRHIND CANAL MAIN LINE LOWER.
(8) AMRITSAR TANK.
(9) SIRHIND CANAL 1914 MAIN LINE LOWER REACH.
(10) SIRHIND CANAL 1914 MAIN LINE UPPER REACH.
(11) SIRHIND CANAL 1916 MAIN LINE LOWER REACH.
(12) SIRHIND CANAL 1916 MAIN LINE UPPER REACH.

rate of absorption was far above that obtained on the Sirhind Canal.

The diagram, which he now put forward, so far as he knew, shewed all the experimental observations carried out to determine the rate of absorption losses. For watercourses and distributaries no depths were available, but the rates of percolation had been given. He did not propose to deal with the question of losses in watercourses, but would suggest that the saturated area of surface soil on each side, in the case of a watercourse, was so much greater in proportion than in a canal (in which more often than not it was nil) that the weight of the factors governing the losses were entirely changed.

Mr. Kennedy's results for the Sirhind Canal had not been published so far as he was aware, but the original results were recorded in the Ludhiana office in his note-book. The first thing noticed was that the observations for the lower reach of the main line were more reliable than those for the upper reach, as the discharges were taken in discharge flumes which were similar, but the result had been obtained from only two discharges at each site. For the upper reach the discharge was gauged in the seven bays of the Budki superpassage ; and a perusal of the instructions issued at the time shewed that orders were given " to guide the rods " from a boat, so that they ran " clear from the piers." This, combined with the fact that the discharge sites were so different, led him to think that the results shewn by Mr. Kennedy should be taken as very approximate.

The author's tank experiment at Amritsar gave a rate of 7·89 cusecs for a depth of 4·2 feet.* It was interesting to note, however, that in establishing his coefficients in the formula he had taken this rate for a depth of 3·8 feet, for he wrote " the rate of absorption from the Amritsar unlined tank would be the same presumably as that from an earthen channel having the same ratio of wetted soil surface to capacity in unit length," but there appeared to be nothing in support of this presumption. In fact it was contrary to his fundamental principle that the losses were in proportion to the head of water pressure. This application of the rate of absorption found experimentally for a depth of 4·2 feet to a 3·8 feet depth, increased his coefficient to 1·33, which, it was submitted, was higher than what was usually accepted.

* Page 18.

Taking column 6 of Table VIII for the Upper Bari Doab Canal it was interesting to see what figure was obtained by calculating out the losses at full supply.

With $Q = c\ d$ (c being unity)	= 1,030
Q = eight cusecs per million	= 1,072
$Q = 1{\cdot}33\ d$	= 1,150
$Q = \Sigma\ c\ a\ d$ for the different reaches, c being taken for each from Table II	= 1,252
$Q = c\ a\ d$, c being taken for the average depth of seven feet given in column 4 of Table VIII	= 1,271

From this it would be seen that had the author utilised his coefficients in the formula he would have obtained very high values. Apparently he had used a coefficient which gave a mean between the results obtained by the use of the coefficient in Table II and the rates usually accepted heretofore.

Mr. E. R. FOY thought that the difference of soil was made quite clear by the variations in the results obtained in different places and that it would be dangerous to assume that the same coefficient would answer in all localities ; and while it might be said that this was already assumed, the present assumption of a uniform rate was one based on practical experience, but what might be good enough for that was not good enough for a scientific formula.

For the purposes of the paper, Mr. Woods had taken * the results obtained from percolation in a tank 4·2 feet deep with a wetted surface of 1,827 sq. ft. having a sinkage of six inches per diem and a loss of 1·77 cusecs per million square feet for each foot of water depth, or with evaporation 1·87 cusecs. In some experiments in connection with lining experiments on the Sirhind Canal the followsng were obtained :—

Depth	11·5 ft.
Wetted surface	3,885 sq. ft.
Absorption	15·4 cusecs

Loss per foot of water depth (including evaporation) 1·34 cusecs.

The tanks were new, but there were thirty-three observations of 14·5 hours each on an average. If he correctly

* Page 18.

understand Mr. Woods' views in the paper, the loss per foot of depth should not be less in one of these tanks than in a 4·2 ft. deep tank, and any formula deduced from those experiments would be upset as regards its value of C if based on the author's figures. The coincidence of a 1·34 figure of loss per foot of depth, obtained on the Sirhind Canal, with a 1·33 coefficient accepted by the author was noticeable, when presumably the latter was deduced from an experiment in which the loss per foot depth was 1·77 cusecs.

MR. BOSTOCK drew attention to the impossibility of measuring the *same body of water* at different points of a canal, as the same body of water never passed any two sections. In practice, the interval of time allowed for the water to reach the lower section was the distance divided by the mean velocity. The case was analogous to a flood coming down a river. The flood slid over the surface of the river and reached any given point long before the time required by the velocity. In practice this did not really matter if the gauges were steady, but, if a gauge were rising, the time interval based on the maximum rather than on the mean velocity would be nearer the mark in order to catch any increments of discharge due to the rising gauge.

RAI SAHIB MAKHHAN LAL stated that from the results of certain experiments made in America which were given in the Transactions of the International Engineering Congress of 1915, it appeared that the formula hitherto used in the Punjab was correct for all practical purposes.

MR. WOODS, in replying, said that he welcomed criticism, for criticism was the breath of scientific progress. He could have wished, however, that his critics had given him beforehand some indication of the lines of criticism which they proposed to follow, so that he might have come to the Congress prepared to deal effectively with the same. It was impossible for him to deal impromptu with arguments involving mathematical calculations, diagrams, and formulæ, but he would ask permission to deal with these later at leisure. For the present he could only deal with such items of criticism as he had been able to grasp during the currency of the speeches of his critics, and such as he could reply to on the spur of the moment.

He welcomed any thing in the nature of data of direct experimental observation by members of the Congress, such as Mr. Nicholson had presented in the course of his speech.

He did not claim precise, or universal accuracy for his absorption formula ; but he contended that it constituted a great advance, in point of accuracy, beyond the formulæ hitherto in use by the profession. Experience might show that the values assigned by him to his coefficient, in the formula $Q = c\ a\ d$, might admit of alteration, or that new and additional factors might usefully be introduced into the formula ; but he hoped that the formula he now proposed would be found to be a useful addition to hydraulic science under present conditions.

Mr. Hadow and Mr. Gibb denied that the loss by absorption varied with the depth of the water in an earthen channel, whilst Mr. Nicholson asserted that the fact that it did so vary had been accepted by the profession for some years, and was in accordance with theory, and with his own experimental observations on the Sirhind Canal. It was well that the discussion should be focussed on this issue, and he had no doubt that Messrs. Hadow and Gibb would in due course perceive that they were wrong.*

They appeared to hold the opinion that the head of pressure governing percolation flow was not the depth of water in the channel, but the distance vertically between the water surface in the channel and the surface of the subsoil water table. Now, in the first place, this idea was not supported by Punjab canal experience, according to which there was no such great difference in the rate of percolation flow from, say, the Lower Chenab Canal, in places where spring level was about a hundred feet below ground surface, and from the Upper Bari Doab Canal, in places where the spring level was less than ten feet below ground surface, as there would be if the head of

* *Extract from a note, dated 11th July 1917, by Mr. B. H. Wilsdon, B.A., Agricultural Chemist, on the progress of the research work conducted at Lyallpur in connection with seepage.*

* * * * * *

2. Under Mr. Barnes, investigation was proceeding on three main lines.

(*i*) Estimation of losses by direct percolation—

(*a*) from canal beds,

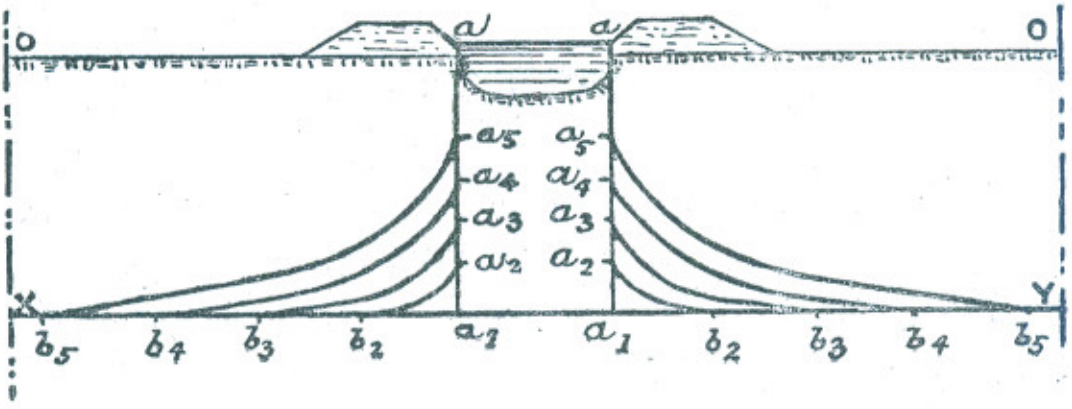
(*b*) in the field under various conditions of irrigation.

For purposes (*a*) and (*b*) drain gauges had been constructed (*a*) under the Rakh Branch at Lyallpur and (*b*) on the hydraulic area at the college farm.

* * * * * *

3. Under (*i*) (*a*) above it has been proved that the rate of percolation through the drain gauge is directly proportional to the head of water in the canal.

pressure, governing percolation flow, were as supposed by Messrs. Hadow and Gibb. The following was a commonsense view of the conditions of percolation flow from Punjab canals, and was supported also by experimental observation :—



Let the line $a\ a$ represent the water surface of the cana shown in cross section above. Before the opening of the canal the surface of the subsoil water table (supposed approximately horizontal) was at XY. When the canal began to flow it is reasonable to suppose that at first the percolation flow from it was vertical, from $a\ a$ to $a_1\ a_1$; for there was no apparent reason why it should flow otherwise than vertically downwards, by gravitation. When, however, it struck the surface of the water table at XY the vertical downward flow was arrested and deflected laterally, and the surface of the subsoil stream assumed a curve, rising successively to $a_2\ b_2$, $a_3\ b_3$, and so on. The lower end of the curve approached the horizontal, tangential to the line XY, whilst the upper end of the curve was tangential to the verticals $a\ a_1$. The water surface gradient of the súbsoil stream varied from point to point along the curves, and he was unable to say what it might be at any particular point, but it was reasonably safe to assume that at the point where the stream originated, at the skin of the channel, the flow was vertically downwards, with a velocity proportionate to the mean head of pressure on the skin of the channel, *i.e.* proportionate to the depth of water in the channel. This was the safest point upon which to base calculations, and there was no need to consider the conditions governing the percolation flow deeper down in the subsoil. No doubt it would be interesting to study the conditions of flow deeper down, as governed by "distance travelled" and by subsoil stream gradients; but for the purpose of *calculating the volume of percolation flow* it

was only in accordance with commonsense to measure it at the point where the factors governing the flow could be most accurately and conveniently measured.

He readily admitted that in places where the level of the subsoil water table happened to be above the level of the bed of the water channel the head of pressure governing percolation flow was not the depth of water in the channel, but was the difference in level between the water surface in the channel and the ground water level. The difference between such a case, and the case of more general application, was merely the difference between a case of "free" discharge and "drowned" discharge through an orifice under pressure.

If one held in one's hands a porous pot containing water, the percolation flow from the pot would be the same, no matter at what level the pot was held so long as it was not submerged in an external reservoir of water. That was the general case with Punjab canals. Mr. Lindley seemed to think that because, in the formula, $Q = c\ a\ d$, c varied as $\frac{1}{R}$, that is, inversely as the hydraulic mean depth, it was permissible to substitute d for R, thereby reducing the percolation flow to a function merely of the area of the wetted surface. That might hold good in the case of very large streams, in which the value of R differed inappreciably from d; and this was pointed out in the paper, where it was shown that the variation of c was very slight and gradua in the case of streams discharging more than 2,000 or 3,000 cusecs, but in the case of small channels the value of R might differ very greatly from d and the effect of this difference was very clearly reflected in the values assigned to the coefficient c in the paper.

Mr. Nicholson had stated that the fact that the rate of percolation varied according to the depth of water in a channel had been accepted by the profession for some years, but that was not a correct statement; for, to the author's knowledge, no other formula for absorption loss had been used within recent years in the Punjab Canal Department than the usual one of eight or ten cusecs per million square feet of wetted surface of channel, mentioned at page 248 of Buckley's "Irrigation Pocket Book." Still it was interesting to learn that according to Mr. Nicholson's own experimental observations the percolation flow *did* vary with the depth of water in the channel, and to note that Messrs. Hadow and Gibb, from *a priori* reasoning, disputed that possibility.

Mr. Nicholson had presented to the Congress a diagram which purported to show that the author's formula could not be correct, but he was unable to keep the Congress waiting whilst he studied this diagram. He was obliged to defer that to a future occasion. What he desired to impress upon the Congress was that a more accurate formula for computing absorption losses than that hitherto in use was desirable. Mr. Kennedy's observations, (or Mr. Higham's), quoted at page 244 of Buckley's "Irrigation Pocket Book," indicated that the absorption losses on the Upper Bari Doab Canal had been found to be :—

On the main canal	... 10·0	cusecs per million square feet of water surface.
On branch canals	... 2·2	
On distributaries	... 3·3	
On watercourses	... 12·5	

It was evident that, if these figures were correct, the ordinary absorption formula of eight cusecs per million square feet of wetted surface must be inapplicable to branch canals and smaller channels. The author's empirical formula, $Q = c\,a\,d$, gave results consistent with the date of experimental observation recorded above and accordingly it constituted a distinct advance in the direction of scientific progress.

CORRESPONDENCE.

MR. LINDLEY, in amplification of his remarks at the Congress, submitted a note subjecting the data presented to what he considered to be the minimum of manipulation necessary to reduce them to a comparable form and pointing out that, where preliminary comparisons indicated a distinct law, this could be allowed for in again reducing the data to the same form. The rate of absorption per million square feet of wetted area and the water depth were deduced in the manner shown below, then tabulated and plotted on the attached diagram. It was evident that unavoidable errors of discharge observations and ignorance of the varying data of channels would make all these data liable to some error, which might be in either a plus or minus direction, but apart from that, the loss in the Amritsar tank experiments, with the sub-soil water-table only $2\frac{1}{2}''$ below the bed of the tank, was bound to be less than if the water-table had been at a greater depth. Higham's experiment was actually made with the

canal running far below full supply, with off-takes closed, and the surrounding soil therefore still, to some degree, soaked to a higher level by greater supplies running before, thus reducing the normal percolation.

The statistical data presented included reaches of canal in which the water-table was high, and in some cases high enough to cause infiltration, but this last did not apply in the case of the Lower Jhelum Canal main line figures, from which the head reach was excluded.

The diagram indicated that the percolation varied with, and was approximately proportional to the depth, only when the group of observations on fields and water-courses was neglected, and there appeared to be no reason for allowing this. Further, as no reason had yet been advanced for holding that the absorption rate in channels of medium size might be less than that in both smaller and in larger channels, the data appeared to support variation of absorption with depth as little as independence of it. More and more accurately comparable data were required before a true law of variation could be empirically derived.

The absorption rates calculated by the author's formula for the typical channels of his Table II* were also shown on the diagram as a dotted line ; and as he had quoted a number of the data as confiming his formula, this diagram showed the effect of employing a different method of comparison.

To summarise—

(*a*) It had been incorrectly assumed that local variations could be neglected and one formula applied to all cases.

(*b*) The proof that percolation should vary with depth in the channel was not acceptable.

(*c*) Conditions had been neglected which might diminish or even reverse flow.

(*d*) The derivation of the formula was devious, and the result unnecessarily complicated.

(*e*) The data quoted did not support the assertion that percolation increased with depth.

MR. LINDLEY'S NOTE.

DYAS' OBSERVATIONS.

The author's assumption that the supply running at the time of these observations was the full supply of the time, 3,000 cusecs, was followed. Lengths had been taken from the data of the experiment and these showed that the observations of the Main Branch Lower, the Kasur Branch, and the Sobraon Branch, included channels subsidiary to them, but their ignorance of what these were made it impossible to use the data of these three channels. The data taken for cross-sections were the averages arrived at by the author in Appendix A, with depths in the Main Line and Main Branch Upper reduced to those corresponding to the lesser discharge, and those in Kasur Branch Upper and Lahore Branch reduced in the same proportion. From these data, wetted areas had been calculated, and the observed absorptions divided by these gave the absorption rates in cusecs per million square feet.

	Main Line.	Main Branch Upper.	Kasur Branch Upper.	Lahore Branch.
Bed width in feet ...	137	106	85	50·6
Full supply depth in feet	8·36	9·90	6·58	5·50
Actual depth in feet ...	5·21	6·16	4·10	3·43
Wetted perimeter ...	151·7	123·4	93·2	57·4
Length in feet ..	142,500	120,000	35,000	300,000
Wetted surface ...	21·60	14·81	3·26	17·22
Absorption	156·75	36·00	22·75	36·00
Absorption rate	7·26	2·43	6·98	2·09

HIGHAM'S OBSERVATIONS.

For the Main Branch Upper and the Main Line combined, the depth and absorption rate had been deduced as above, but the data were insufficient for any use to be made of the Main Line Lower observations.

Bed width in feet	...	123	Full supply depth in feet	...	9·05
Actual depth in feet	...	4·63	Wetted perimeter	...	136
Length in feet	...	315,000	Wetted surface	...	37·4
Absorption	...	272	Absorption rate	...	7·28

KENNEDY'S OBSERVATIONS.

Absorption rates had been given by the author in the last column of Table I on page 7. The depths taken were, for virgin soil and for cultivated land the mean of 0·6 and 1·0 given by the author as the maximum and minimum; for water-courses, the average given by the author; for rajbahas, a figure verbally given to the writer from the original data.

STATISTICS.

The full wetted area had been calculated from the author's figures instead of the reduced wetted area, and the statistical absorption divided by the mean depth had been taken.

LOWER JHELUM CANAL.

The absorption loss of the main line had been fixed by taking sufficient observations to keep the discharge curves correct at several points, but at present it could only be said that with a supply of 3,750 cusecs running with a depth of eight feet on a bed-width of 140 feet, giving 19·75 millions feet of wetted surface in a length of twenty-one miles, the loss in winter appeared to be between 185 and 210 cusecs, giving an absorption rate of about 10.

Observations were made on watercourses throughout the canal system and those made by Mr. L. Hammond in April 1916 on the Pakhowal distributary, near Malakwal, in the Jhelum Bar, which had been irrigated for fifteen years were reproduced below.

No. of water-course.	Reduced distance.	Area.	Perimeter.	R.	Discharge.	Wetted area.	Loss.	Absorption rate.
1	1,000	1·19	2·96	0·40	1·08	10,200	0·16	15·7
	4,000	1·80	3·85	0·46	0·92	14,800	0·42	28·5
	8,000	1·32	3·56	0·37	0·50			
2	1,000	4·20	8·43	0·49	2·86	19,700	0·34	17·3
	4,000	3·60	5·69	0·63	2·52	29,600	0·13	4·4
	8,000	7·70	9·12	0·84	2·39			
3	1,000	1·45	3·15	0·46	1·29	10,200	0·01	1·0
	2,800	0·81	2·48	0·33	1·28			
5	1,000	1·775	3·65	0·48	1·26			
	4,000	3·49	5·35	0·65	1·15	13,500	0·11	8·2
	?	2·85	5·17	0·57	1·08			
6	1,000	3·60	5·12	0·70	2·27	15,400	0·35	22·7
	4,000	3·85	5·21	0·73	1·92	20,600	0·03	1·5
	8,000	2·93	5·10	0·57	1·89			
9	1,000	2·15	4·11	0·52	1·52	12,400	0·13	10·5
	4,000	2·17	4·13	0·52	1·39	14,400	0·24	16·7
	8,000	1·20	3·06	0·39	1·15			
12	1,000	2·15	3·95	0·543	1·97	12,300	0·12	9·8
	4,000	2·57	4·24	0·605	1·95	19,400	0·13	6·7
	8,000	3·59	5·47	0·655	1·72			
13	1,000	2·55	4·21	0·605	1·52	15,000	0·07	4·7
	4,000	4·10	5·76	0·710	1·45	19,400	0·04	2·1
	8,000	1·52	3·95	0·385	1·41			
14	1,000	2·46	4·35	0·566	1·38	12,200	0·10	8·2
	4,000	2·325	4·89	0·475	1·28	17,700	0·28	15·8
	5,700	1·69	3·96	0·426	1·00			
Totals and means ...				0·540	...	227,800	2·73	9·8
Excluding all above mean $\times \frac{3}{2}$ or less than mean $\times \frac{2}{3}$						135,700	1·31	9·7

had come to the conclusion that he who dared to read a paper to an audience like that must indeed be a brave man. He felt that he himself would be very much afraid to express himself at all on any scientific theory, and he admired the courage of those who were willing to do it. He admired the spirit which was really the life of all scientific progress : the spirit of free criticism. Those scientific investigations for which it was evident there was such great scope, had a great potential economic value. On a moderate computation, it seemed that each cusec of canal water was capable of adding eight thousand rupees to the national wealth. If it were true that forty-three per cent. of the supply at the head was lost by absorption in the channels, and that not more than one-third of the balance was actually made serviceable for the growth of plant life, the possibility of increasing the produce of agriculture by the successful application of the results of enquiry in this one direction were almost unlimited. The true test of the value of water was, no doubt, the value of the crop which it produced, and not merely the revenue which it brought to Government. At the same time they had to recognize that it was essential, when Government was borrowing, that it should be in a position to prove that the return it would receive would justify the incurring of the debt.

In concluding the speaker wished to emphasise how great a privilege it had been to him to be allowed to listen to the discussions which had taken place.

SIRDAR BAHADUR LAHNA SINGH, referring to the concrete slabs proposed for the Sirhind Canal, considered that if large tiles two to three feet long and about sixteen inches wide, such as were manufactured in Lahore and Saharanpur, were substituted, the cost per hundred square feet would be appreciably reduced. The joints could be made in cement or some bitumastic substance, to make them water proof.

MR. CURRY in reply said that he had been very interested in the remarks made by Mr. Foy, and hoped that the proposals to line some of the new branches of the project under preparation in the Sirhind Canal would be carried through. They would afford a true criterion of the respective advantages and disadvantages of such a policy.

As regards the water rate per cusec, and the net profit per cusec of head discharge, the figures were taken from the Administration Report, and were open to check. Concerning the mixtures described on page 44, he had been unable to visit that particular canal, and consequently he had made inquiries by

letter. He had misunderstood the reply he had received, and was grateful for the correction. No reflection on the properties of the Indian Portland cements had been intended. He had assumed that there was a stock of English Portland cement which it was considered desirable to use up. His own experience was that the Secretary of State's Portland cement had not always been all that might be desired. Regarding the Narwala experiments, he apologized for not having furnished the exact details, but he could not find the files. The experiment was about to be repeated, and the results would then be checked.

Mr. Gibb had criticised the formula used and the variable co-efficient, but when he first began thinking about this paper he felt he had to base his arguments on some formula, and Mr. Woods's formula was the best available. Mr. Woods had already said that he was open to any alteration to his formula, and he believed that experiments of various kinds were being carried out to confirm it. As an example they might take the drain gauges on the Lower Chenab Canal.

With reference to the economic value mentioned by Mr. Gibb, one of his points was that they ought to pause and consider whether they could achieve the same results at a cheaper cost.

Regarding Mr. Nicholson's remarks on the results of the lining already laid in various channels, he admitted that no results were available. For the past three years, the water levels in a number of wells along the Jhang Branch had been observed, and the results of the lining were therefore only available for this period, but these results, such as they were, gave cause for optimism. The average subsoil water level along the lined reach was less last year than in the previous two years, but the results required further checking.

Regarding his figure of Rs. 8,064 as the value of a cusec of water per annum, it was only a question of arithmetic, and it had been shown in the paper how this figure had been arrived at.

Replying to Mr. Duthy's remarks, the sand used on the Jhang Branch was of a fine variety. In his estimate of the cost of linings the shrinkage might be accepted as thirty-three per cent., which would raise the cost of the cement-sand lining to Rs. 22 per hundred square feet. The cost of railing and carrying the cement, and of placing it in a godown, was included in the estimated stock rate for the cement.

If the godowns and water reservoirs were close to the lining site, and the mixing was done on the spot, the remaining provision ought to be sufficient.

Mr. Morris had advocated the exploiting of Indian made Portland cements, and no doubt this would be taken up when the industry had been further developed, and possibly the home variety would be outrivalled.

Mr. Woods had succinctly reviewed the points raised in the paper, and the difficulties involved in lining canals, and he thought Mr. Woods's views most useful.

He had been very pleased to hear Mr. Faulkner, and to listen to his interesting opinions. He had presented a non-departmental view of the subject, but his proposal for a six weeks closure of a canal was impracticable. His own experience had been that where irrigation was intense, they could not spare water for a day. Under present conditions, on the Lower Chenab Canal, each cultivator received water in turn, and in the winter months only received water once a month. If the canal were closed for six weeks, the last man in a chak would not receive water for ten weeks, by which time, in the absence of rain, his crops would be ruined.

Even allowing that the canal could be closed for six weeks, only three miles of the main channel could be lined in that time, and as the total length was forty miles it would take thirteen years to line the main canal alone.

Sirdar Lahna Singh had made a useful suggestion, which might be considered by the officers of the Sirhind Canal.

In conclusion he begged to be permitted to express the pleasure they all felt at the presence of Mr. Maynard at the Congress, and to thank him for his interesting and encouraging remarks regarding the future possibilities of irrigation.