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“Discharge of Main Drains in Lower Egypt.”

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THE reclamation of the waste lands of Lower Egypt involved a careful study of the question of drainage as well as of irrigation. No figures were available as to the actual discharge in cubic metres per feddan¹ per day from perennially-cultivated land. In designing drains, hitherto, empirical figures and a large margin of safety had been used, but as the proposed drainage schemes involved the construction of drainage pumping-stations, these rough and ready methods were no longer economically applicable. The north of Lower Egypt, the Delta proper between the two branches of the Nile, is drained by eleven main drains, numbered consecutively beginning from the east. Of these, Nos. 1 and 2 discharge direct into the sea, about 25 kilometres west of Damietta. The others all discharge into Lake Borrallos, which is connected with the sea by a very narrow opening, and is, therefore, little affected by the small tide of the Mediterranean. During the summer the lake falls, as the discharge of the drains decreases owing to diminution of irrigation. As the water-level during the winter in the lake and main drains is higher than the land, it is obvious that the land cannot drain naturally by gravitation. It has been decided that the main drains are to be kept at a low level by Government pumps at their outfalls, and the subsidiary drains gravitate into these. To ascertain exactly what size pumps are needed for this, the drainage discharge in cubic metres per feddan per day had to be determined.

From July, 1911, regular discharges, at intervals of about a week, were taken of drains 5, 6, 7, 8, 9 and 11. Drains 1, 2, 3, 4 and 10 for various reasons were not measured. The discharge sites on each drain were chosen as near the mouth as possible, and on a straight clean reach, with no curves, bridges, inlets, or other obstructions, up-stream or down-stream, to affect the flow of the current. The

¹ 1 feddan = 4,200 square metres.

discharges were determined by means of surface floats (bottles), the distance of travel being 50 metres.

To ensure that the maximum surface velocity was measured, six or more velocities were taken in the centre, C, of the stream, and also at points A and A' midway between the centre and each bank. If the velocities at A A' are equal to each other, and less than that at C, it is safe to assume that the velocity at C, the centre, is the maximum surface velocity, and Bazin's formula is therefore applic-

Fig. 1.

able. The cross-sections were very accurately measured by sounding before each discharge, the level of the water-surface being determined from a bench-mark established close to each site. The horizontal interval between successive soundings was measured along a rope stretched over the drain.

The discharges were always taken in the early morning, as it was found that the wind is then at its calmest, and the float would not be affected by it.

Method of Estimating the Area Drained.—An irrigation system

consists alternately of canals and drains. The catchment-basin of any drain is the area contained between the two canals, one on either side of it. The catchment-basins of the various drains under consideration are shown on the map (*Fig. 1*). These areas were planimetered off 1/50,000 Survey maps. The Survey maps show also the village boundaries, and the area of each village is accurately registered in the Mudirieh (provincial headquarters). The area of the villages in every catchment-basin was added as a check, and agreed very well with the area obtained by planimeter. The total area drained by each drain was thus determined very accurately. But, on the drains under consideration, only a portion of the whole area is under cultivation, the rest being uncultivated "boor." The administrative irrigation circles were able to furnish figures showing the area actually supplied with field drains, for when a cultivator wishes to make any private drain with outfall into a public drain, a licence is granted by the Irrigation Service, giving the diameter of pipe and the area drained. Some cultivators endeavour to raise crops without making field drains. The area is small in comparison with the total area on any drain, and is better included under "boor" than under cultivated land. In any case there is no means of determining the cultivable area more accurately than this, and the error introduced is small and of the same order as that in the actual discharge measurements. In the Mudirieh, there is registered every year, with considerable accuracy, the total area of summer crops in each village area. The total is given, and also the area under each kind of crop (cotton, rice, etc.). These figures were supplied by the Mudirieh, and the area served by each drain is shown in Table II in the Appendix.

Rice in Egypt requires twice as much water in summer as ordinary dry crops, and is given twice as much. In calculating the summer water duty, each feddan of rice is reckoned as equal to 2 feddans of dry crops.

Thus on drain No. 6:—

	Feddans.
Total area of summer crops including rice	74,900
Area of rice	5,436
Total equivalent area	80,336

During flood and winter all cultivable land receives as much water as it needs, rice not more than the other crops.

The figures obtained for run-off in cubic metres per feddan per day are not applicable to single feddans, but only to large areas drained by a main drain. A main drain serves an area of say

100,000 feddans (cultivated). The whole of this area is not under irrigation at the same time. The canals in one district may be running low, while those on another are running full supply. The discharge of individual feddans varies with the irrigation, the main drain averages the total discharge of the whole area. Table III (Appendix) gives the results of the discharge observations on drain No. 5 (*Fig. 2*). The mean sectional velocity is calculated from

Fig. 2.

DRAIN No. 5.

the maximum surface velocity by means of Bazin's formula:—

$$V = c U,$$

where V denotes the mean velocity over section;

U „ the maximum surface velocity and also central surface velocity;

c „ a constant, depending on R , the hydraulic mean depth,

and n is Kutter's roughness coefficient.

It is important to note that Bazin's formula is only applicable where

the maximum surface velocity is at the centre of the surface. The formula is applicable to the drains in question, as they are originally artificial channels and their cross-sections on straight reaches, however deteriorated from the original, are still symmetrical. Manning's coefficients are used in the above formula, and $1/n$ was taken equal to 40 (ordinary canals), or 33 (weedy drains). The coefficients used are given in Table I. The area of cross-section (A) and wetted perimeter (P) were measured, and the hydraulic mean depth (R) thus determined, and D, the discharge, calculated. Drains Nos. 6, 7, 8, 9 and 11 were calculated in the same manner, and the results are given in the discharge-date curves. The slope was then calculated from Manning's formula, the coefficient of roughness being taken as 0.025.

Assuming that the discharge from cultivated land is C cubic metres per feddan per day and from "boor" land B cubic metres per day, that the cultivated area on any drain is A_c and the boor area A_B , and that the total discharge of the drain is Q cubic metres per day, there results for each drain an equation of the form—

$$C A_c + B A_B = Q.$$

Now A_c , A_B , and Q are known for each drain. A mean equation is obtained for each drain, and the most probable values of C and B deduced by the method of least squares. The observations in July cannot be used for calculation, for at that time the "boor" land is dry, and there is only sufficient water in Egypt for part of the cultivable area. Hence $B = 0$, and there is obtained a value for C in summer. The area irrigated in summer is known with considerable accuracy, hence from the July observations the drainage discharge in summer can be determined very accurately. Towards the beginning of May every year, a decree is issued forbidding the irrigation of any land not under cultivation at that date. This is known as the "Sharaki" decree, and is not removed till the end of July, when the flood rises. From the removal of the Sharaki decree, fallow land is gradually brought under irrigation, until, towards mid-September, all cultivable land is under irrigation and the boor areas are being swamped. Hence, in the equations, A_c and A_B are increasing daily, and it is impossible to deal with the equations in any way until they have attained a steady value in September. In 1911, the Sharaki decrees were repealed on the 16th July for area drained by drains Nos. 5 and 6, and on the 20th July for Nos. 7, 8, 9 and 11, and the area irrigated did not become constant until about the 20th September. The gradual increase in the discharge of the drains is shown on the curves of discharge-date. The values of the discharge in cubic metres

per feddan per day in summer, as calculated from the first series of discharges, are shown in the following Table:—

DISCHARGE IN SUMMER.

Drain.	Date.	Quantity.	Total equivalent Area, Summer, 1911.	Discharge.
		Cubic Metres per Day.		Cubic Metres per Feddan per Day.
5	17/7/11	102,816	26,148	3·9
6	18/7/11	167,616	80,336	2·1
7	22/7/11	96,768	15,952	6·1
8	24/7/11	..	21,155	..
9	25/7/11	80,352	24,492	3·2
11	26/7/11	330,912	27,589	11·9

It will be seen that the results are somewhat discordant. This is due to the fact that the Sharaki decree had already been repealed a day or two before the discharge of the drains was taken, which was therefore on the increase. The discharge of drain No. 11 is very great owing to the escape of canals into it, and shows how important it is carefully to regulate the supply in the canals if drainage has to be lifted by pumps. Neglecting the results of drain No. 11, the other four give a mean of 3·8 cubic metres per feddan per day as the discharge in summer for ordinary crops, and 7·6 cubic metres per feddan per day for rice. The supply of water in Lower Egypt in 1911 was about 26 cubic metres per feddan per day. According to the above figures, about 4 cubic metres per feddan per day was taken by the drains, and the remainder must have been evaporated unless the subsoil table rose. The latter eventuality is highly improbable during the summer, and it must be assumed that 22 cubic metres per feddan per day was evaporated. This is equivalent to the evaporation of 5·2 millimetres depth of water per day, a very reasonable figure, if anything a little on the low side. It seems probable, then, that 4 cubic metres per feddan per day may be taken as the drainage discharge of cultivated land during the summer in Lower Egypt. Turning to the flood and winter discharges, all the observations up to mid-September were neglected, as the area under irrigation was increasing daily. By mid-September, all the area was irrigated, or if any were left fallow, the fallow area would be the normal winter proportion.

The discharges for each drain between mid-September and the end of December were divided into two parts, as it appeared that

The unit of area was taken as 10,000 feddans and the following equations were obtained:—

Drain.	Equations.	Quantities in the Different Cases.							
		First Half.		Second Half.		All.		Maximum.	
5	5.1 C + 0.0 B =	6.7	R. 8.0	5.1	R. 6.4	5.9	R. 7.3	7.4	R. 9.0
6	7.5 C + 9.4 B =	15.1	16.1	12.2	12.3	13.7	14.2	16.7	17.9
7	2.6 C + 4.7 B =	6.4	6.2	3.9	4.7	5.1	5.4	7.3	6.9
8	3.0 C + 2.2 B =	7.2	5.7	4.2	4.5	5.7	5.1	7.8	6.4
9	4.1 C + 2.0 B =	9.8	7.4	8.1	5.7	9.0	6.6	11.0	8.2

The left-hand sides of the equations do not change, as the areas of cultivated and "boor" land remain the same. These give four groups of five equations to determine the values of the two variables B and C in each group. By the method of least squares the following results are obtained. The quantities in the columns headed R in the Table of equations above are the discharges for the drains, computed from the deduced values:—

Observations.	Values of		Values per Feddan per Day.	
	B	C	B	C
	Cubic Metres per 10,000 Feddans per Second.		Cubic Metres.	Cubic Metres.
First half	0.453	1.573	3.9	13.6
Second half	0.305	1.251	2.6	10.8
All	0.366	1.432	3.2	12.4
Maximum	0.486	1.768	4.2	15.3

During March, 1912, a series of discharges was taken at various sites on drain No. 7. Four sites were chosen at intervals of a few kilometres along the drain and the area drained, up-stream of each site, was determined. Up-stream of the sites at kilometre 40.5 and kilometre 34.5 no boor land is drained. Up-stream of the site kilometre 28 a small area of boor is drained and kilometre 13 is the same site as that used in the other observations, and here the drain serves a large area of "boor" land.

It is impossible to determine with accuracy the actual proportion of the cultivable area that is under cultivation, inasmuch as some of the winter crops are still being irrigated and the watering of

some of the summer crops has already begun. There is sufficient water in March for all needs, but not a surplus as there is in flood. The fellah has to be moderately careful and waste as little as possible. From such figures as are available from finance statistics, it is probable that about half the cultivable area is under cultivation in March.

Table IV in the Appendix gives the result of the discharge observations taken in March, 1912. The mean of the discharges at each site was taken, and the unit of the area being 10,000 feddans, the following four equations were obtained:—

Site.	Weight.	Equations.	Observed.	Computed.
K. 40.5	5	$1.1 A_c =$	0.083	0.20
K. 34.5	5	$1.8 A_c =$	0.144	0.33
K. 28	4	$2.5 A_c + 0.2 A_b =$	0.790	0.54
K. 13	6	$2.6 A_c + 4.7 A_b =$	2.177	2.19

The above equations give discharges in cubic metres per second per 10,000 feddans and the results are converted to discharges in cubic metres per feddan per day. Each equation is weighted according to the number of observations it represents, and the four equations are solved as before and give—

C = 1.61 cubic metre per feddan per day for cultivable land.

B = 3.13 cubic metres per feddan per day for boor land.

If it be assumed that half of the cultivable land is under irrigation and the other half dry (as is the fact), then—

C = 3.23 cubic metres per feddan per day—cultivated land;

B = 3.13 cubic metres per feddan per day—boor land;

i.e., the discharge from cultivated land is found to be doubled, as might be expected. The results obtained can now be tabulated as discharges per feddan per day, remembering that the unit of area used in the experiments was 10,000 feddans.

From March to May the discharge from boor land must diminish rapidly, as the water supply decreases and the land dries up.

The discharge from cultivated land remains very nearly constant in spring and summer. Since in spring the discharge is only 3 to 4 cubic metres per feddan per day, although there is sufficient water, it seems highly probable that this is the true drainage discharge and that the extra discharge found in the drains in the flood

SUMMARY OF RESULTS.

	Discharge in Cubic Metres per Feddan per Day.	
	Cultivated Land.	Boor.
Summer	3·8	Nil.
September and October (rising flood)	13·6	3·9
November and December (falling flood)	10·8	2·6
September to December (mean for the whole flood)	12·4	3·2
Maximum (in October)	15·3	4·2
Spring (March)	3·2	3·1

is due to waste of water, to over-watering, to running field-irrigation ditches direct into drains (instead of closing them at the head), and to escaping canals into drains. This means that from September to December there is three times as much water in the drains as there need be. It is unnecessary to dwell on the immense economy that could be effected in pumping costs, in size of drains, and in maintenance of drains by restricting water-supply in flood—which can be done by strict remodelling of all pipe-outlets, if free-flow irrigation is given—or by suppressing free-flow irrigation altogether and compelling the fellah to lift all his irrigation water: he will not lift more than is absolutely essential. In connection with drainage-pumping, it has been feared that large capital expenditure might be necessary to provide pumps capable of coping with the extra water in drains due to the sudden rainstorms which occur during the winter in the north part of the Delta. When such storms occur, first, the fellah closes his irrigation outlets, the rain providing the irrigation water, and even if the canals are at once closed at the heads, for a time there will be a large excess of water in them, which can only be discharged into the drains. Secondly, the rainstorm, it is feared, may in itself give more water than the fields require, and from this cause, too, the drainage discharge be increased. These rainstorms, however, occur in December and January. From a glance at the discharge-curves (*Fig. 3*), it will be seen that there is a fall in the discharge in the first half of December, corresponding with the end of the irrigation of the flood crop, and then a rise in the second half of the same month, due to the application of a last heavy watering before the 40 days winter closure of canals for clearance purposes. During January and until the middle of February, the discharge is practically nothing.

December, January and February are the months of heavy rainfall, and during these months the drains are low and should be capable of discharging the sudden overflow from the tails of canals. Dry Nile mud absorbs 50 per cent. of its volume of water, therefore, taking the mean between dryness and saturation, average Nile mud will absorb 25 per cent. of its own volume. Hence a fall of 75 millimetres of rain will be absorbed by the top 30-centimetre layer of soil. The highest recorded fall of rain is 76 millimetres in 24 hours at Alexandria on the 7th October, 1876. (This is a very abnormal time of year for such a rainfall and there are no records to show how widespread it was.) Normally speaking, rain-falls of high intensity are not widespread and will not affect the whole drainage-area of a large pumping-station. From these considerations it appears that the provision of extra pumping-plant to cope with rainstorms is unnecessary: (1) Because the storms occur, normally, at a time when the drains are running below their maximum. (2) Because a large proportion will be absorbed by the soil and only gradually drained off.

The rainfall data are taken from an article in the *Cairo Scientific Journal* for April, 1912, by Mr. J. I. Craig, M.A., of the Egyptian Survey Department, to whom the Author's thanks are also due for his mathematical treatment of the experimental results to obtain from them the most probable values.

The Paper is accompanied by eight drawings, from which the Figures in the text have been selected, and by the following Appendix.

[APPENDIX.

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TABLE I.—MANNING'S COEFFICIENTS.

(From "Elementary Hydraulics," Willcocks and Holt, Cairo.)

Values of c_1 in the formula $V = c_1 U$ for reducing maximum surface velocity to mean velocity.

R in Metres.	Very Clean Canals. $\frac{1}{n} = 50$	Ordinary Canals. $\frac{1}{n} = 40$	Weedy Drains, etc. $\frac{1}{n} = 33$
0.60	0.77	0.72	0.68
0.70	0.77	0.72	0.68
0.80	0.78	0.73	0.69
0.90	0.78	0.74	0.70
1.00	0.78	0.74	0.70
1.50	0.79	0.76	0.71
2.00	0.80	0.77	0.72

TABLE II.—AREAS ON DRAINS NOS. 5, 6, 7, 8, 9 AND 11, SUMMER, 1911.

Drain.	Discharge Site.	Total Area drained.	Total Cultivable Area.	Total "Boor" Area.	Total Area cultivated Summer, 1911.	Rice Area Summer, 1911.	Total Equiv- alent Area Summer, 1911.	Ratio Total culti- vated Area to "Boor" Area.
5	K. 0.500	Feddans. 50,929	Feddans. 50,929	Feddans. ..	Feddans. 24,412	Feddans. 1,736	Feddans. 26,148	..
6	K. 2.250	168,901	74,900	94,001	74,900	5,436	80,336	0.80
7	K. 12.700	72,692	26,041	46,651	14,000	1,952	15,952	0.58
8	K. 1.200	52,479	30,267	22,212	17,000	4,549	21,155	1.37
9	K. 2.700	61,272	40,830	20,442	20,917	3,575	24,492	2.00
11	K. 4.000	46,875	37,992	8,883	20,974	6,615	27,589	4.28

TABLE III.—SUMMARY OF DISCHARGE OBSERVATIONS ON DRAIN No. 5.

Date.	Maximum Velocity.	Mean Velocity.	A	P	R	D	$\frac{1}{n}$	S
17/7/11	0·09	0·07	18·1	15·2	1·19	1·19	40	Centi- metres per Kilom.
28/7/11	0·08	0·06	16·4	14·8	1·10	0·98	40	
6/8/11	0·06	0·04	16·2	14·7	1·09	0·65	40	
15/8/11	0·21	0·16	20·0	16·0	1·25	3·20	40	1·0
23/8/11	0·27	0·20	20·2	15·6	1·30	4·04	40	1·7
1/9/11	0·28	0·21	19·6	15·3	1·27	4·11	40	2·0
10/9/11	0·31	0·23	22·8	16·2	1·41	5·25	40	2·0
21/9/11	0·34	0·25	23·5	17·2	1·36	5·87	40	2·5
2/10/11	0·38	0·29	23·62	16·2	1·45	6·85	40	3·0
11/10/11	0·28	0·21	23·62	16·2	1·45	4·96	40	1·6
22/10/11	0·40	0·30	26·15	18·8	1·39	7·94	40	3·6
29/10/11	0·30	0·23	30·1	21·2	1·41	6·92	40	2·0
9/11/11	0·30	0·23	30·8	21·3	1·44	7·08	40	1·95
14/11/11	0·30	0·23	30·1	21·2	1·41	6·92	40	2·0
21/11/11	0·30	0·23	25·8	18·9	1·36	5·93	40	2·1
27/11/11	0·28	0·21	25·2	16·8	1·49	5·39	40	1·5
1/12/11	0·25	0·19	22·9	16·2	1·42	4·35	40	1·2
10/12/11	0·25	0·19	25·1	18·6	1·35	4·93	40	1·0
13/12/11	0·25	0·19	25·5	18·7	1·36	4·84	40	1·0
17/12/11	0·27	0·20	26·4	19·1	1·38	5·27	40	1·8
22/12/11	0·26	0·20	26·9	19·2	1·40	5·33	40	1·5

TABLE IV.—DISCHARGE OBSERVATIONS ON DRAIN 7 IN MARCH, 1912.

Boor area	46,451 Feddans.	2,000 Feddans.		Nil.		Nil.	
Cultivable area . }	26,041 Feddans.	25,225 Feddans.		18,192 Feddans.		10,980 Feddans.	
Site . .	Kilo. 13.	Kilo. 28.		Kilo. 34.5.		Kilo. 40.5.	
		Date.	Cubic Metres per Second.	Date.	Cubic Metres per Second.	Date.	Cubic Metres per Second.
	..	..	..	8/3/12	0.158	3/3/12	0.117
	..	..	..	..	..	..	..
	11/3/12	3.10	9/3/12	..	..	..	..
	..	..	..	..	..	12/3/12	..
	15/3/12	2.96	15/3/12	13/3/12	..	..	..
	19/3/12	1.38 ¹	19/3/12	17/3/12	0.196	17/3/12	0.096
	23/3/12	1.90 ¹	23/3/12	21/3/12	0.14	21/3/12	0.077
	27/3/12	1.75 ²	27/3/12	..	..	25/3/12	0.072 ²
	31/3/12	1.97	..	27/3/12	0.14 ²	..	..
			..	29/3/12	0.088	29/3/12	0.058
Mean . .	..	2.177	..	..	..	..	0.083

¹ Strong north wind. ² Strong south wind.