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EDWARD WOODS, President,
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“Irrigation in Lower Egypt.”¹

By WILLIAM WILLCOCKS, Assoc. M. Inst. C.E.

OWING to the absence of rain, the agriculture of Lower Egypt depends entirely on irrigation. In Upper Egypt, where the basin system of irrigation prevails, the country along the banks of the Nile is divided by extensive dykes into a series of basins, varying in size from 50,000 to 8,000 acres each. These basins are filled with water from the Nile in August and September and emptied in October. Shakespeare gives an exact account of the system of agriculture :—

“They take the flow o’ the Nile
By certain scales i’ the pyramid; they know,
By the height, the lowness, or the mean, if dearth
Or foison, follow: The higher Nilus swells
The more it promises: as it ebbs, the seedsman
Upon the slime and ooze scatters his grain,
And shortly comes to harvest.”

The crop of wheat, flax or beans, is sown without ploughing in November, and reaped in March. During the summer, from April to July, countless temporary wells are dug, which supply water by means of shadoofs, to excellent crops of millets, cucumbers and melons. This is the system of irrigation Nature meant for Egypt; yearly the rich slime is renewed, and the soil still retains the fertility for which it has been famous since the earliest times. In Lower Egypt all this is changed. Here the year is divided into three seasons, corresponding with the phases of the Nile and the changes of the climate. The first season is the “séfi,” or summer, which extends from the 1st of April to the end of July, while the Nile is at its lowest. At this time the discharge of the Nile varies from 12,000 cubic feet per second, in a bad year, to 25,000 cubic

¹ See “The River Nile.” By B. Baker. Minutes of Proceedings Inst. C.E. vol. ix. p. 367; and “Notes of a Journey through the N.E. portion of the Delta of the Nile in April 1884.” By W. Anderson. Minutes of Proceedings Inst. C.E. vol. lxxvi. p. 346.

feet per second during an exceptionally good one, the average discharge being 14,000 cubic feet per second. The summer crops are cotton, rice, sugar-cane, melons and cucumbers, while clover is irrigated up to the beginning of June. The summer is followed by the "Nili," or flood season, which lasts through August, September, October and November, when maize is grown. The flood crop of maize is the staple of food for the whole agricultural population. During the floods, besides the maize, cotton, rice and sugar-cane are irrigated and matured, and the fallow land, of which there is very little, is put under water. At this time the maximum Nile discharges vary from 187,000 cubic feet per second during a year of low Nile, to 387,000 cubic feet per second during a year of very high Nile. The third season is the "Chitawi," or winter, during the months of December, January, February and March. The winter crops are wheat, beans, barley and clover. A discharge of from 25,000 cubic feet per second to 55,000 cubic feet per second can be depended on during the winter.

Taking the Deltaic provinces of Menufieh and Garbieh, with which the Author is directly concerned, the importance of the different seasons may be thus compared :—

Total area paying taxes = 1,170,000 acres.

Summer Crops.

	Acres.	£.
Cotton	390,000, yielding	3,600,000
Sugar-cane	3,000 "	36,000
Vegetables	3,000 "	30,000
Rice	35,000 "	245,000
Total	<u>431,000</u> "	<u>3,911,000</u>

Flood Crops.

	Acres.	£.
Maize	560,000, yielding	2,240,000
Flood rice	30,000 "	60,000
Total	<u>590,000</u> "	<u>2,300,000</u>

Winter Crops.

	Acres.	£.
Tobacco	3,000, yielding	21,000
Flax	2,000 "	20,000
Vegetables	7,000 "	70,000
Wheat	320,000 "	1,600,000
Barley	170,000 "	340,000
Beans	120,000 "	600,000
Clover	380,000 "	1,140,000
Total	<u>1,002,000</u> "	<u>3,791,000</u>

Practically the whole area yields a double crop, which may be valued at £10,002,000. It is not pretended that the above figures are exact; they embody the result of three years' study and observation. To accomplish this irrigation there are employed 11,708 water-wheels, 1,123 portable engines with a joint HP. of 9,895; and 162 stationary engines with a joint HP. of 2,395. The summer crop is the most difficult and expensive to raise; while the great task of the irrigation engineers in Lower Egypt is to supply and distribute the water fairly. To obviate difficulties imposed on summer irrigation by the low level of the Nile, Mehemet Aly began the Barrages at the head of the Delta in 1835, under the able direction of Mougel Bey; and had it not been for the *corvée*, or forced labour, he would have finished them. The presence of the *corvée* enabled the Government at first to dig the canals deep and dispense with the Barrages; and when afterwards difficulties arose owing to inferior workmanship, which inferior work Mougel Bey was compelled to execute in a hurry, it seemed easier to the Government to keep on calling out the *corvée* than to face the problem of the Barrages and definitely solve it. To these deep canals Egyptian irrigation owes all its difficulties. Canals meant to irrigate small tracts of land, and needing during flood a bed width of 10 feet and a depth of 6 feet, have bed widths of 10 feet and depths of 20 feet. They run 3 feet deep in summer, and suffice for the summer crop, which covers about one-third of the whole area commanded. During flood they irrigate the whole area, but have to run 20 feet deep in order to ensure flush irrigation along their entire lengths. The result is that regulators have to be built at intervals of 8 or 10 miles along the canals, and closed during flood to bring the water to the surface of the land. This converts the canals into a series of pools, which form very efficient silt traps. The checking of the velocity causes the Nile mud to settle in the beds of the canals in deposits of 8 feet and under on hundreds of miles. This has to be removed yearly by the *corvée* at enormous cost. Hundreds of acres of valuable land lie buried under thick deposits of mud, while the fields themselves lose this rich mould. But this is only the beginning of evils. In spite of the closed regulators, and numerous other contrivances, the canals are so disproportionately large during flood, that they send down into the lower lands further north such an excessive volume of water, that all the canals, escapes, and drainage cuts are full to overflowing with flood-water, and are in consequence unable to perform their proper functions. The country during flood is divided into a number of islands surrounded by water at a

high level. The natural consequence is that salt efflorescence is greatly on the increase in the lands under cultivation; while 300,000 acres of land in Garbieh, capable of being reclaimed by drainage and basin treatment, are maintained in a state of swamp. Owing besides to the existence of so many regulators, about 2 per cent. of which are provided with locks for navigation, the canals are no longer the magnificent highways for the conveyance of produce which they once were. Indeed, many poor lands are not cultivated at all, because the cost of transport is prohibitive.

The deep summer canals are supplemented in floods by a network of shallow canals, which run only during high Nile. The Nile begins to rise about the 1st of July, but in this month the rise is not generally sufficient for flood irrigation, which begins usually about the 10th of August. Early in August the rise attains an average daily rate of 1 foot, until the maximum of 20 feet above summer level is reached. At this stage of the Nile it is from 3 to 8 feet above the level of the country, which is protected from inundation by dykes. As soon as the water is high enough to flow into the flood canals, the sowing of maize begins, and is continued to the middle of September. The maize is sown very close together and is gradually thinned as it grows, providing food for the cattle during this season of the year. The early-sown maize yields twice as much corn as the late. For flood irrigation, therefore, an early rise of the Nile is the best. The Nile at Assouan reaches its maximum about the 20th of September, and would, under ordinary circumstances, be at its highest in Lower Egypt about the 25th of September; but as the basins of Upper Egypt are being filled in August and September, the Nile in Lower Egypt is only moderately high. Between the 1st and 10th of October, the basins are opened, and the Nile in Lower Egypt is at its highest about the 15th of October. A high Nile at Assouan, about the beginning of October, omens ill for Lower Egypt, as the addition of water from the basins means excessive floods. By building proper regulating works among the basins, and opening them with precision, it will be possible to supplement a low flood, and prevent a high one from being dangerous. The end of the floods is contemporaneous with the reaping of the maize crop, which is followed by a final heavy irrigation of the whole country, and the subsequent sowing of the wheat crop after ploughing, and the clover without ploughing.

It will now be easy to comprehend that the problems before the irrigation engineer in Lower Egypt are the following :—

1. The strengthening and securing of the Barrages, so as to ensure a constant high-water level during summer.

2. The construction of escapes and supplementary flood canals, so as to irrigate during summer from the summer canals, and during high Nile from flood canals, and thus prevent slime deposits.

3. The obtaining of a flood-supply as early as possible in the canals.

4. The drainage of the lowlands, and their restoration by means of basin irrigation to their original fertility.

5. The conversion of the salt plains near the inland lakes into cultivable land.

6. The protection of the Nile dykes during flood.

7. The opening of routes for navigation, so as to convey the produce of the fields cheaply to the markets.

8. The regulation of the water-supply.

The Author will confine his remarks to the provinces of Menufieh and of Garbieh, which, with the Barrages, formed the circle under his charge during 1884 and 1885 :—

1. THE BARRAGES.

In January, 1884, the Author would have thus described the two Barrages. The Nile Barrages are open dams thrown across the heads of the Rosetta and Damietta branches, at the apex of the Delta. Of the two branches the Rosetta has nearly twice the flood-supply of the other, while its bed is some 6 feet lower; on it are placed two pumping stations for supplying the Béhéra province with water during summer. The Damietta branch feeds eight important canals. The Rosetta Barrage is 1,437 feet between the flanks, and the Damietta 1,709 feet. These Barrages are separated by a revetment wall 3,280 feet in length, in the middle of which is situated the head of the Delta Canal. The platform of the Rosetta Barrage is flush with the river bed, being 29·8 feet above mean sea-level. Its width is 151 feet and depth 11·5 feet. It is composed of concrete overlaid by brick and stone work. Downstream of the platform is an irregular talus of rubble pitching, varying in places from 150 feet to 10 feet in width, and from 50 to 2 feet in depth. The left half of the platform is laid on loose sand, the right half on a barrier of rubble pitching overlying the sand. This loose stone barrier is 30 feet high, 200 feet wide at the deepest part, and tapers off to zero at the ends. It closes the original deep channel of the river, and its only cementing material is the slime deposit of the Nile. This deposit is so excellent that the barrier

is practically watertight. The platform supports a regulating

ROSETTA BRANCH BARRAGE, January 1884.

Scale $\frac{1}{3,000}$.

It is proposed to make the remodelled high summer level 14.60 metres, at present it is 13.60 metres, above mean sea.

bridge with a lock at each end. The bridge consists of sixty-

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one openings, each 16·4 feet wide; the lock on the left flank is 39·4 feet wide, while that on the right is 49·2 feet. Fifty-seven of the piers are 6·6 feet wide, while three of them are 11·6 feet wide; their height is 30·2 feet. The lock walls are 9·8 and 14·8 feet wide. The piers support arches carrying a roadway and a system of fortifications. The two locks are provided with drawbridges and fortifications. Taking 62·6 feet as the high flood-level, the waterway of the Barrage is 34,359 square feet, while the high-flood discharge is 225,000 cubic feet per second, causing a banking up of 0·8 foot. The concrete of the platform is considered inferior, while Mougél Bey, the builder, condemns that under the ten openings from No. 48 to No. 57, owing to the hurry in which he was compelled to complete it. The floor here settled 0·4 foot during the floods of 1867, producing a deflection in the superstructure both horizontally and vertically. These ten openings are enclosed within a cofferdam 16·4 feet high and 6·6 feet broad, composed of a wooden framework packed with stone, resting on the platform. Of the sixty-one openings, forty-seven are regulated by means of iron gates, and the remaining fourteen by vertical wooden piles resting against oak horizontals. The iron gates are each 16·4 feet broad and 19·7 feet high; shaped like the arc of a circle, and supported at either end by iron rods radiating from the arc to the centre; here they are attached to massive iron collars working round cast-iron pivots embedded in the masonry of the piers at the centres of the arcs. The curvature of the arcs is down-stream, and the pivots are consequently up-stream, of the gates. Powerful crabs, travelling on rails at the roadway level, raise and lower the gates by means of chains attached to the bottoms of the gates. The iron gates and wooden piles when lowered do not reach the platform of the Barrage; they rest on iron gratings 1 foot high, fixed into the piers just above the platform. These gratings allow of a free passage of the water when the gates are down. They were originally put in to prevent deposits of slime in front of the gates. It is reported that men have been sucked through the foundations of the Barrage; it would be more correct to say that they have been drawn through these openings.

The Damietta Barrage has ten openings more than the Rosetta Barrage, of 16·4 feet each. The platforms and superstructures are on the same level and exactly similar. No records exist of the state of the foundations, but Mougél Bey states that the work here is excellent, since it was practically built in the dry. This Barrage is partially supplied with wooden horizontals, but has never

been used for regulation. The 49-foot lock is unprovided with gates.

Previous to 1884 the Barrages were regulated in the following manner :—When the Nile gauge stood at 43 feet,¹ which generally happened in March, the Rosetta Barrage gates and piles were quickly lowered to their full extent, beginning at opening No. 1, and closing at opening No. 61. The consequence was a rapid current through the last openings just before they were closed. It was on one of these occasions that the ten openings from No. 48 to No. 57 were injured, according to the report of the Egyptian foremen on the work. The Government report states that they were injured during the floods of 1867, owing to contracted waterway. As soon as the gates and piles reached the gratings they could descend no further, and the work of regulation was at an end for that year. The up-stream gauge rose to 44·6 feet, while the down-stream gauge fell to 38·9 feet; so that, with a difference in water surface of 5·7 feet, there was a gain in water-level of only 1·6 foot. This was due to the fact that the Damietta Barrage was open. Of the water which escaped through the Rosetta Barrage, practically the whole found its way through the iron gratings. These gratings, with a head of 5·7 feet, were capable of discharging over 8,000 cubic feet per second. The river kept falling through April, May, and June, and during the whole of this time the Damietta Barrage was open, as well as the gratings of the Rosetta Barrage. There was not sufficient water in the Nile to allow of a head of 5·7 feet on the latter, and it fell to 3·3 feet. Towards the end of June the up- and the down-stream gauges roughly indicated 41·3 feet and 38·1 feet respectively. If the Rosetta Barrage had failed in June, the loss of head in the Delta canals would have been 1 foot. When the Nile began to rise in July, and the up-stream gauge read 44·6 feet, the gates were raised as quickly as possible, the river fell to 43 feet, and was allowed to recover as the flood rose. This it did generally in six or eight days.

After an inspection of the Barrages in January 1884, and a comparison of previous gauges, it was determined to maintain above the Barrages a constant gauge of 44·6 feet. This resolve was supported by the following considerations :—

The studies of Mr. (now Sir John) Fowler, Past-President Inst. C.E., had proved that the brickwork on the surface of the platform was good, however inferior the concrete substructure might be.

The severe action below the Barrage when a gate was lowered to

¹ All levels are reduced to "mean sea."

its full extent, was found to be due to iron gratings, or "windows" in the foundation, and not as it had been supposed to a honey-combed foundation. This fact was apparently unknown to the writers of the reports on the Barrages. Indeed it ought to have been evident that if all that action was due to fissures in the foundations, the Barrage would have been swept away years ago.

The Okhla dam at Delhi on the River Jumna, a mass of loose rubble stone with absolutely no foundation, holds up yearly 10 feet of water, when the water-pressure per lineal foot bears to the weight of the dam a proportion of $\frac{3,125}{129,600}$ or $\frac{1}{40}$. Nile sand is much finer than that in the Jumna, and will therefore require a lower coefficient; but this is a difference of degree and not of kind.

Considering the Barrage a thoroughly unsound work, and relying only on friction, it was determined to make the submerged weight of masonry bear a ratio of 50 to the pressure of the water going to be brought on it. Springs might cause a slight subsidence of any part of the Barrage, but it could not be moved as a whole. The pressure of a head of 10 feet of water would be 3,125 lbs. per lineal foot. The submerged weight of the platform was 103,983 lbs. per lineal foot. The coefficient between them was $\frac{1}{33}$. That this proportion might be $\frac{1}{30}$, it was necessary to make the rubble talus everywhere 131 feet wide, and 10 feet deep, with a submerged weight per lineal foot of 51,668 lbs. This made the submerged platform and talus together 155,651 lbs. as compared to the pressure of 3,125 lbs. Since only $\frac{1}{3}$ of the talus was completed in 1884, the Barrage was not required to hold up more than 7.2 feet of water; on the completion of the talus in 1885, 10 feet of water were held up.

About the end of January 1884, the river gauge fell to 44.6 feet. From this date the gates and piles were gradually lowered in the Rosetta Barrage, so as to maintain this gauge. When the gates reached the gratings, and the piles were driven home, the work of closing the gratings was taken in hand; while the talus was strengthened with 671,015 cubic feet of rubble pitching. Owing to the incomplete state of the talus no more than 7.2 feet of water were held up on the Barrage. Attention was now directed to the Damietta Barrage, which was strengthened with 494,432 cubic feet of rubble pitching; the left flank lock was closed with a stone dam, the right lock was repaired and opened for navigation and a channel for boats dredged to and from it; and all the openings were provided with oak horizontals and sheet-piles, and gradually closed. At this juncture Nubar Pasha, at Colonel Moncrieff's request,

gave a special grant of £18,000 over and above the ordinary budget, and so enabled the work to proceed without interruption. Eventually at the end of the season, the Rosetta Barrage held up 7·2 feet, and the Damietta 3·3 feet, while the water-surface above the Barrages was 44·6 feet instead of 41·3, as it would have been under the ordinary method of working. On the 7th of July the Nile began to rise; on the 13th of July the Damietta Barrage was opened, and the Rosetta between the 18th and 31st.

The Nile at Assouan during the summer of 1885 was lower than it had been in 1884, and almost similar to what it was in 1882.

FIG. 2.

ASSOUAN GAUGE (Southern Boundary of Upper Egypt).

Scale 1 cubit = 54·04 centimetres = 1·773 foot.

The Author has therefore plotted the Nile curves at Assouan (Fig. 2) for 1882 and 1885, and also at the Barrage (Fig. 3), for comparison. It will be seen that the water-surface above the Barrages in 1885 was 4·1 feet higher than what it was in 1882. During 1882 a discharge of 1,720 cubic feet per second entered the Delta Canal; during 1885 there was a uniform discharge of 4,200 cubic feet per second. This year the talus was completed with 1,271,399 cubic feet of rubble pitching, and a small temporary stone dam was raised on it, with its crest at reduced level 38·05 feet, so that the Barrage might hold up 6·7 feet, and the

stone dam 3·3 feet, or 10 feet of water between them, the pressure being distributed. This dam was removed before the flood, and the materials were added to the talus. The wooden horizontals were found untrustworthy in both Barrages, and rolled-iron beams were substituted. The cofferdam round the ten weak openings was considerably strengthened. Eventually the Rosetta Barrage held up 10 feet, and the Damietta Barrage 5·6 feet, of water. The Nile began to rise on the 5th of July, and the Barrages were completely opened by the 24th.

During 1886 Mr. Perry, who had been Resident Engineer in 1884 and 1885, was put in charge of the Barrages, and worked on

FIG. 3.

BARRAGE GAUGE. UP-STREAM.

Zero of Barrage Gauge 60 centimetres above mean sea.

the same lines as in 1885, with the same results. The work of repairing the Barrages out of the £1,000,000 loan was begun this year under Mr. A. Reid, of the Public Works Department of India, and the floors of five openings were exposed, examined, and made watertight. This work will be prosecuted with great vigour in 1887, at the end of which year it will be possible to give a detailed account of the system of protection adopted.

Besides regulation, the training of the Nile on to the Barrages has been steadily pursued, the Government granting £3,800 per annum for the work. The works have been in progress three years, and it is expected that in another two years the original

scheme will be completed. This consists in bringing the Nile flood on to the apex of the Delta, and there distributing the supply. The apex has been fixed at a point about $2\frac{1}{2}$ miles up-stream of the Barrages. Individually the Author would have preferred making the head of the Delta Canal (at the middle of the revetment wall) the apex, but in this he was overruled. However, the steady pursuit of the present plan will overcome all difficulties and gain the desired end, if only it is adhered to. In January 1884 the whole Nile was flowing along its left bank to the Rosetta Barrage, at about $\frac{1}{4}$ mile above which the waters were divided, two-thirds of the supply passing down the Rosetta branch, while the remaining one-third ran along the revetment wall between the two Barrages, and so reached the Damietta branch. The latter was practically a spill-channel for the Rosetta branch. Sir Charles A. Hartley, K.C.M.G., stated, in 1877, that if something were not done in the direction of river-training, the Damietta branch of the Nile would silt up, just as five out of the seven ancient mouths of the Nile had done during the course of the last eighteen centuries.

2. SLIME-DEPOSITS.

With respect to the reduction of slime-deposits in the canals, the raising of the water-surface above the Barrages has already done much in this direction, but much remains to be done. The expenditure on some of the canal clearances was extravagantly high compared with the results obtained from the clearances. The greatest offenders in the Delta were the Sahel and Nagár canals. The annual cost of the former was £15,000 for *corvée* labour, and gave a summer discharge of 80 cubic feet per second; the cost of the latter was £18,000, and gave a discharge of 40 cubic feet per second. Pumping-engines, delivering water at a 12-foot higher level, would have delivered 600 cubic feet of water per second into each canal for the same money. As the *corvée* expenditure, however, did not appear in the Budget, public attention was not directed to it, as it would otherwise have been. The accompanying plans (Figs. 4 and 5) show the work done on the two above-mentioned canals. The Nagár Canal, with the Sabbal and Nenaiah, formed one system of summer canals. Out of these canals the *corvée* cleared, in 1884, 31,906,388 cubic feet of slime, at a cost of £45,172. After the remodelling works were put in hand, the clearances were reduced to 3,727,913 cubic feet in 1886, costing £6,334, while it is anticipated that in 1887 the clearances will fall to 1,059,500 cubic feet, costing £1,800.

The remodelling works have cost altogether £15,000, and, with the higher level of water at the Barrage, have practically done away with the slime-clearances altogether. Referring to Fig. 4, the double lines show the original summer canals, and the single lines give the new flood canals, which now accomplish the whole of the flood irrigation. During high Nile the summer canals are partially

FIG. 4.

closed at their heads, and the supply of water sent down suffices for the flush irrigation of the low lands in the lower reaches. The regulators, numbered 1, 2, 3, 4, are unused, and all surplus water is discharged down the two new escapes marked A and B, which tail into the Nile. The water now is always in motion, and the slime cannot be deposited in the canals. A party of engineers is employed in taking fortnightly discharges of all the canals, com-

paring the discharges obtained from surface-velocities with the discharges obtained from surface-slopes, and measuring the depths of slime or sand deposited in each fortnight. The observations are still in progress, but it has been already established that a velocity of over 2 feet per second in August and September, when the Nile water is much charged with slime, prevents deposits, not only of slime, but even of sand. In October far lower velocities suffice,

FIG. 5.

since the Nile water is diluted with the clear basin-water of Upper Egypt. Fig. 5 gives the Sahel, Khadarawiah, and Átaf system, which originally were fed from the Nile during both summer and flood. By excavating, at a cost of £9,000, the new summer canal A B C, which is fed by the main Delta Canal during summer from above the Karanaia regulator, at any level that may be considered convenient, the slime-clearances are dispensed with. During flood the canals take their water direct from the Nile. The prin-

ciple on which all the changes are made is that summer irrigation, both as to its channels and sources of supply, must be kept quite distinct from flood irrigation.

3. EARLY FLOOD SUPPLY.

Next in importance to a plentiful supply of water in summer is the securing of an early supply in July and August, in order to ensure a good maize crop. The equatorial rains of Central Africa and Abyssinia reach Egypt late, owing to the great length of the Nile, while winter in Lower Egypt sets in early; time, therefore, is of great importance. To secure an early flood supply, a new regulator is necessary at the head of the Bahr Shebín. At its 14th mile the main Delta Canal divides into two branches; of these the left branch is known as the Bahr Bajoor, and the right as the Bahr Shebín. During August the Nile Barrages are open, and the water in the Nile and the main canal is at the same level. By building a regulator at the head of the Bahr Shebín, and closing it in August, the whole supply coming down the main canal will be turned down the Bahr Bajoor, while the Bahr Shebín will take its supply direct from the Nile. By utilizing existing works and channels, and spending £16,000, it will be possible to nearly double the water-supply of the two central provinces during the rise of the Nile, and so secure an early maize crop everywhere. For besides the extra value of an early maize crop itself, it is very desirable that the final flood-watering, which prepares the land for the winter crop-sowing, should be given when the Nile water is high enough for flush irrigation. Since the Nile falls very quickly after the 20th of October, the sooner the maize crop is off the ground the less is the chance of there being any necessity to lift water by machinery for the winter crop.

4. BASIN-IRRIGATION FOR THE LOW LANDS NEAR THE SEA.

The two preceding paragraphs have reference to the country for a distance of 65 miles north of the Barrages. The next belt, of 15 miles in width, was in former days, judging from the ruins of towns and villages, as fertile as the first; it is now very different. When cotton-cultivation was introduced, about forty years ago, all the fields in this tract were planted with cotton, and produced fairly well; gradually the lower fields fell out of cultivation, owing to salt efflorescence and lack of drainage. As the higher fields were now required to produce a double share of an exhaustive crop, while they received no manure or slime-deposit,

they had to be planted with cotton and rice alternately, to prevent their complete deterioration. The drainage water of the rice fields was run on to the lower lands, and completed their ruin. New canals, dug without levels or alignment, and the conversion of all the drainage cuts into irrigation canals, was all that was needed to destroy the higher lands. This soon followed. In many places now, the tops of the old banks and the beds of the old canals are the only places which yield a crop at all. Still, with a persistency worthy of a better cause, the cultivation of cotton is insisted on, and here and there a wretched peasant may be seen ploughing up the bed of a contracted drain or canal in the middle of a vast salt plain. The only remedy for this is a return to the basin system. It seems ridiculous that during the summer months, when the water has no fertilizing property, and there is very little of it, landowners should go to the greatest expense to lift it on to a dozen fields from among a thousand. These few fields they have to toil at through the year, and when the flood comes, with rich fertilizing water in plenty, and at a suitable level for irrigation, thousands of watchmen are turned out to guard the dykes which keep it within its banks, and prevent it from reaching the land it covered in old days. If the country were divided into basins, and the flood-water allowed to inundate them, there would be deposited a rich soil, which, without ploughing and without irrigation, would yield a magnificent crop, a hundredfold more valuable than the sickly rice or cotton now produced. It must be possible to restore to this land the fertility it once enjoyed under the Pharaohs, who were acquainted with no arts which moderns do not possess, but under whom what is now a desert was then a garden, and what are now numberless ruins were populated towns and villages. Since nothing better than the Pharaonic system of basin-irrigation is known, it has been attempted to re-introduce it on a large scale; while all the old drainage cuts are being thoroughly deepened and cleared, and prevented from being used any longer as canals. Considerable ameliorations must result from the intelligent pursuit of a system which answered so admirably in Upper Egypt for thousands of years.

5. BASIN-IRRIGATION FOR THE LANDS BORDERING THE LAKES.

The belt of land north of this last tract is, if possible, still worse. Here a fresh evil has cropped up. Through neglect of ancient dykes and ancient systems of regulation, the sea has been allowed to mingle with the Nile water, and the two combined

have been driven by the prevailing N.W. winds over the flat low-lying land. This tract is composed of barren salt plains, from which rise numberless mounds strewn with bricks and pottery. The canals here have no dykes, and though the Nile water itself, unmixed with salt, pours over some of the plains, no crop is produced except on the edges of the canals, where all the slime is deposited owing to the want of basins. The whole country appears to be inundated by the red muddy water of the Nile, but stepping out of a boat and walking away direct from the canal, it will be found that the water is red for a few hundred feet, after that it is colourless, and then black and stagnant, blasting the land it covers. The lands inundated by the red water produce a crop, the rest yield a coarse grass or are barren. If the summer supply in the Nile were sufficient for the irrigation of all the land, it might easily be converted into one extensive rice-field; but as this supply is available in one year only out of fifty, it is useless to consider proposals of reclamation by superior rice-culture, and recourse must be had to the basins which are filled during the flood. It may be noted in passing that the Nile flood arrives too late to mature a good rice crop; there is a coarse quality of rice produced by the flood, but the yield is so insignificant that the lands so cultivated pay no revenue.¹ The area of land capable of being reclaimed in Garbieh alone is over 600,000 acres, and as 10s. per acre is the tax paid by inferior land in Egypt, the project seems worth a trial. A sum of £10,000 has already been spent in so reducing the flow of the canals into Lake Borillos, that its summer area of 160,000 acres will not be increased to 490,000 acres in flood-time as heretofore. Last year over 18,000 cubic feet per second entered the lake; this year barely 5,000 cubic feet per second. Dykes and drains are under construction, while the opening between the lake and the sea is being watched to see the effect of the decreased supply.

6. NILE PROTECTION.

Previous to 1884 it was customary to protect the reaches of the Nile, where the scour was severe, with rubble pitching spread

¹ The summer or superior rice known as "Sultáni" gives twice as large a yield as the flood or "Sabáini" rice, while its price is one and three-quarter times as high. The latter, however, might be much improved by careful culture. If the lands were ploughed in summer and exposed for three months to the sun, sown with Sabáini rice at the beginning of the flood, and carefully weeded during flood, the yield and quality would both be improved, while the lands themselves would be partially reclaimed.

over the slopes. This practice has been discontinued, as it was only a temporary expedient and had no permanent effect. The stone has now been collected at suitable sites, and the nucleus of spurs begun. Yearly the money allotted for Nile protection is spent in adding to these spurs. In a dozen years they ought to completely protect the banks, as the sum allotted is a handsome one. Besides the above purely protective works, training works are in progress in many places. Owing to the enormous quantities of sand and clay brought down by the Nile flood, at a velocity which can just keep the liquid moving, the slightest impediment produces heavy deposits, and renders the work of river-training easy and effective.

7. NAVIGATION.

The most important navigation works in hand are the ten new locks under construction; their cost is to be defrayed from the £1,000,000 loan, under the direction of Major Western, R.E., Assoc. Inst. C.E. Besides making the principal canals in the Delta navigable along their entire lengths, they will keep open the through traffic between Cairo, Alexandria, and Damietta during the summer, when the Nile branches are not navigable. In addition to the above main lines of communication, some of the subsidiary canals are being taken up; but the work of combining navigation, drainage and irrigation, with their conflicting interests, is so difficult and costly, that the Author is inclined to the idea that light tramways would pay better, provided any company could be found to construct them, without demanding concessions of through lines competing with the Government railways.

8. REGULATION OF WATER-SUPPLY.

In order to ensure a fair distribution of water during summer, the approximate areas of summer cultivation on each canal have been tabulated; gauges erected at the heads of the minor canals, and the regulators of the main canals, and discharges measured fortnightly, and proportioned to the areas cultivated. The regulating heads of all the minor canals have been repaired sufficiently to allow of speedy opening and closing, while the main canal regulators have been thoroughly renewed. To complete the system, a new regulator and lock have been built in the main canal at a cost of £21,000. The gauges to be maintained up-stream of the main canal regulators, and down-stream of the minor canal

heads, have been determined. The utilizing of the main canal regulators during summer has resulted in a great reduction of silt-clearances in the minor canals. Formerly the Government refused to allow a single regulator on the main canals to be touched during summer. The Government wanted to regulate from Cairo, and thought that the safest way to prevent unscrupulous men in the district from closing off too much water was to keep the regulators open. By this means the authorities certainly gained this end; but the silt-clearances rendered necessary on all the minor canals, in order that summer-water might be taken in at a low level, were a heavy burden on the *corvée*. By using the regulators, the silt-clearances have been reduced to one-fifth of what they were, while the water distribution has been improved. For now the minor canals have their water-level from 1 foot to 2 feet below that in the main canals, and it is therefore easy to increase or to reduce supply whenever necessary. Summer irrigation is far more indispensable for the low lands at the tails of the canals, than it is for the rich lands at their heads. Of the 1,170,000 acres in the second circle, about 850,000 acres are capable of producing, between the 1st of August and the 31st of May, two excellent crops, one crop of maize during the floods, and the other of wheat, beans, or clover during the winter. To the inhabitants of such lands cotton is a luxury; they can pay their taxes without cotton. The remaining 300,000 acres are incapable of producing maize owing to dampness; but they can produce good cotton and rice, and to such lands therefore as much water as possible should be sent down during the summer. Up to the present, it has been difficult to do anything in this direction, since the landholders at the heads of the canals have been encouraged to think that they have a right to put up pumping-engines wherever they feel so inclined. All increased supplies of water resulting from future improvements should be sent on to the lands incapable of producing maize.

The level of water in the Damietta branch of the Nile, at the heads of the two great systems of canals fed by that branch, has been raised during summer by dams of loose stone. Each dam contains about 500,000 cubic feet of stone, and has cost £5,000. The dams hold up 3 feet of water during summer. Their crests are lowered towards the end of July, and the floods pour over them without any signs of afflux. The crests are renewed yearly in April at a trifling cost. The Rosetta branch of the Nile near the town of Rosetta is closed yearly, at a cost of £8,000, with an earthen dyke which holds up $2\frac{1}{2}$ feet of water, and during summer keeps out the sea, which, on the Egyptian coast, never rises more

than 2·5 feet under the actions of tides and storms combined. The dyke is swept away at the beginning of each flood. All the above works must be continued till the Barrages are repaired.

The regulation of water for summer irrigation is thrown into great confusion, about the 15th of July, by the cultivators on the summer canals taking water for their maize before the flood has really come. Flood-irrigation, properly speaking, begins when the water is high enough to flow into the flood canals, which ordinarily takes place about the first week of August. Not satisfied with waiting for the flood, the larger cultivators on the summer canals, from about the 15th of July, work their engines and water-wheels night and day, while the smaller ones turn out with kerosene tins worked as shadoofs, and a dozen other contrivances, to irrigate their lands and put in maize. Since the area under irrigation is trebled, while the supply of water at the heads of the canals is unaltered, there results, as a natural consequence, a very serious deficiency of supply at the tails of the canals. Near the tails of the canals are situated all the rice-fields, a crop which cannot stand a ten days' closure without injury. Tales of the incapacity of the Irrigation Department form, therefore, the ordinary topics of conversation in Lower Egypt from the 15th of July to the 7th of August. For it must be remembered that though the Nile is rising, the water-level above the Barrages is constant, while all the extra supply coming down the Nile helps to swell the two branches below the Barrages. When both the branches are filled, and the Barrages completely opened, the real rise begins. Not ten Egyptians outside the Public Works Department realize this. At present, owing to the absence of any canal law, the only action which the irrigation officers can take is to close with earthen banks for ten or fifteen days all the canals which irrigate only cotton; but as many of the cotton-irrigating canals have rice at their tails, matters are complicated. The cotton crop in July can easily stand a fifteen or twenty days' closure. Indeed it seems to be improved by it, as the drought kills the cotton worm or addles the eggs. At this season, the Author thinks it would be better to allow the water at the up-stream gauge at the Barrage to rise from 44·6 feet to 47·9 feet, taking care that the amount of water held up was not more than 10 feet. During flood the regulation is easy; but as the cultivators have been accustomed to a steady supply at this season, they object to the periodical openings of the regulators. The regulators are opened in order to generate a current and to remove the slime deposits. Time will conquer this objection. During winter all the masonry

works are repaired, and the canals cleared, for the coming summer. The irrigation work is easy.

The staff of Egyptian engineers employed on the work has invariably given the most efficient and ready help. To their cheerful co-operation is due whatever success has attended the measures adopted in the direction of proper regulation.

The Author concludes this Paper by remarking that in Upper Egypt, where the old Pharaonic system of basin-irrigation exists, every acre of land is cultivated and pays revenue, while the soil is as rich to-day as it was thousands of years ago. In Lower Egypt, on the contrary, where the improved system of irrigation prevails, and a triple crop is gathered, one-third of the area is uncultivated, while the remaining two-thirds are incapable of paying a higher revenue than Upper Egypt. The improved system, besides, has only lasted some fifty years, and yet there is a cry of the deterioration of the soil and produce from one end of the country to the other—a cry which is re-echoed by English cotton-spinners. Nature wants the slime of the Nile flood to be deposited on the land; it is now forced into the sea; and though it is not necessary to go to the full extent of Napoleon's statement, that were he master of Egypt he would never allow an ounce of slime to be wasted, yet it may be stated, without fear of contradiction, that for every £1 of profit resulting from the expenditure of £1,000 on the improvement of the existing irrigation system, £10 would be the return on money spent in a partial restoration of the basin-system where the lands are cultivated, and a complete restoration where the lands are not under cultivation.

This Paper is accompanied by several diagrams, from which the Figs. in the text have been engraved.

APPENDIXES.

APPENDIX I.—HYDROGRAPHIC MAP OF THE PROVINCES OF MENUFIEH AND GARBIEH, LOWER EGYPT, 1887.

FIG. 6.

Scale $\frac{1}{1,600,000}$.

Contours 3 feet apart above mean sea.

APPENDIX I.—HYDROGRAPHIC MAP OF THE PROVINCES OF MENUFIEH AND GARBIEH, LOWER EGYPT, 1887 (Fig. 6).

Total length of summer canals	1,431 English miles.
" " flood canals	747 " "
" " drainage cuts	174 " "
Maximum flood Rosetta Branch	225,000 cubic feet per second, 1878.
" " Damietta "	162,000 " " "
Minimum " Rosetta "	116,000 " " 1877
" " Damietta "	71,000 " " "
Cultivated land, Menufieh and Garbieh	1,170,000 acres.
Cultivable "	670,000 "
Sandhills	250,000 "
Lake Borillos in summer	160,000 "
<hr/>	
Total area of the two provinces	2,250,000 "
High-flood level at the Barrages	62.6 feet above mean sea.
Ordinary summer level above Barrages	44.6 " "
" " " below Rosetta Barrage	34.6 " "
" " " Damietta "	39.0 " "
Slope of Rosetta Branch in flood near the Barrages	$\frac{1}{11,000}$, velocity 4 to 5 feet per second.
Slope of Damietta Branch in flood near the Barrages	$\frac{1}{13,000}$, velocity 3 to 4 feet per second.

The ordinary discharge available at Cairo in summer is 14,000 cubic feet per second. Of this discharge 10,500 cubic feet per second are now utilized in irrigating 1,155,000 acres in the Delta during summer. When the Barrages are completed the whole 14,000 cubic feet per second of water will be used in irrigating during summer 1,540,000 acres. Since the cultivable area of the Delta exceeds 5,500,000 acres, the reclamation of Lower Egypt or the Delta by summer irrigation is impossible. Flood irrigation alone can be depended on for reclamation.

Of the 1,170,000 acres in Menufieh and Garbieh, 431,000 acres are irrigated in summer. During flood the summer crop and 590,000 acres of flood crop are under irrigation. In winter 1,002,000 acres are sown with winter crops. There is practically a double crop every year.

In summer about 4,250 cubic feet of water per second enter the canals of Menufieh and Garbieh; during flood 17,500 cubic feet per second; and during winter 6,000 cubic feet. During flood and in winter all the canals discharge into the sea or lake at the tails.

During flood and in summer there is no rainfall. In winter there is a slight fall of rain in the northern half of the Delta, and a little at Cairo; but practically none in the southern half of the Delta.

During summer and flood it is assumed that the evaporation is $\frac{1}{4}$ inch in twenty-four hours.

The level of the springs rises and falls with the Nile. In summer it is about 12 feet below the surface at the head of the Delta, and gradually reaches the surface at Lake Borillos. At that time of the year each branch of the Nile is fed by infiltration water at the rate of about 600 cubic feet per second.

Near the Barrage the slope of water surface in the Rosetta Nile is greater in summer than in flood; in the Damietta Nile, on the contrary, it is greater in flood than in summer.

APPENDIX II.—DETAILS OF SOME CANALS IN THE DELTA (Figs. 7).

SCALE HORIZONTAL & VERTICAL 2000

SCALE HORIZONTAL & VERTICAL 1000

SCALE HORIZONTAL & VERTICAL 1000

APPENDIX II. (Figs. 7)—continued.

APPENDIX II.—DETAILS OF SOME CANALS IN THE DELTA OF EGYPT (Figs. 7).

Canal.	Season.	River level.	Bed width.	Depth of Water.	Area.	Slope.	Velocity per second.	Discharge per second.	Observations.							
Main Delta canal at head	{Flood .	{53·0}	{174}	{20}	Square feet. 3,652	$\frac{1}{15,000}$	Feet. 2·97	Cubic feet. 10,846	{The Delta main canal receives 3,943 cubic feet per second from this head, and 250 cubic feet per second from another feeder during the summer, irrigation performed by minor canals.							
	{Summer}	{43·0}														
Main Delta canal on Bahr Shebin at tail	{Flood .	{16·0}	{72}	{6}	1,010	$\frac{1}{15,000}$	2·25	2,272	{Closed by an earthen bank at the tail during summer.							
	{Summer}	{8·0}														
Sirisawiah canal at head	{Flood .	{48·1}	{20}	{7}	650	$\frac{1}{20,633}$	1·75	1,138	{During flood the second regulator is opened every alternate week and the velocity increased.							
	"	{34·5}														
	{Summer}															
Nagr canal at head	{Flood .	{48·4}	{20}	{10}	453	$\frac{1}{14,000}$	2·00	906	{Remodelled supply; same alternate regulation as above. Irrigation performed by minor canals.							
	"	{43·9}														
	{Summer}															
Sahel canal at head	{Flood .	{41·4}	{20}	{12}	613	$\frac{1}{25,641}$	1·60	981	{Remodelled supply.							
	{Summer}	{32·9}														
Subk flood canal .	Flood .	48·2	13	6	114	$\frac{1}{20,000}$	1·00	114								

When the velocity is less than 1·8 foot per second in flood, silt is deposited. During summer there is no silt deposit as the water is clear.

APPENDIX III. (Fig. 8).—DISCHARGES AND MEAN VELOCITIES OF THE ROSETTA AND DAMIETTA BRANCHES OF THE NILE BELOW THE BARRAGE.

Fig. 8.

Calculated from slope and cross-section, and verified by surface velocity observations, by Major Webster and Mr. A. Reid, using Bazin's coefficients.

Maximum flood this century at Barrage.

Downstream gauge: Rosetta, 18'25; Damietta, 18'50.

Minimum flood this century at Barrage.

Downstream gauge: Rosetta, 15'25; Damietta, 15'40.

APPENDIX IV.—MAXIMUM AND MINIMUM NILE THIS CENTURY DURING FLOOD (Fig. 9).

Fig. 9.

1877. Nile too low for Upper Egypt basins. Famine caused Ismail Pasha's deposition.
1878. Nile banks breached. Inundations in Lower Egypt.

UPSTREAM BARRAGE-GAUGE CURVES.

APPENDIX V.—EARTHWORK EXECUTED IN MENUFIEH and GARBIEH (SECOND CIRCLE OF IRRIGATION) from 1883 to 1886.

	1883.			1884.		
	Corvée.	Paid Labour.	Total.	Corvée.	Paid Labour.	Total.
No. of corvée on earthwork . . . }	5,143,075	..	..	4,685,465	..	..
Money value of above corvée in £ . . . }	205,728	..	..	187,418	..	..
Cubic feet of out-turn work by . . . }	250,437,260	..	..	149,132,600	..	..
" of work by paid labour . . . }	..	..	..	..	27,357,000	..
Cost of paid labour, £ . . . }	..	..	..	..	17,849	..
Total work by corvée and paid labour in cubic feet . . . }	..	..	250,437,260	..	..	176,489,600
Total value of earthwork . . . £ . . . }	..	..	205,728	..	..	205,267
No. of corvée on Nile Protection . . . }	3,065,420	..	..	455,300	..	..
Money value of above corvée . . . £ . . . }	91,963	..	91,963	13,659	..	13,659
Total cost of earthwork and Nile Protection . . . £ . . . }	..	..	297,686	..	..	218,926

	1885.			1886.		
	Corvée.	Paid Labour.	Total.	Corvée.	Paid Labour.	Total.
No. of corvée on earthwork . . . }	824,008	..	..	2,042,324	..	..
Money value of above corvée in £ . . . }	32,960	..	..	81,673	..	..
Cubic feet of out-turn work by . . . }	12,768,893	..	..	29,237,648	..	..
" of work by paid labour . . . }	..	59,185,310	..	..	62,922,200	..
Cost of paid labour, £ . . . }	..	46,369	..	..	39,223	..
Total work by corvée and paid labour in cubic feet . . . }	..	..	71,954,203	..	..	92,159,848
Total value of earthwork . . . £ . . . }	..	..	79,329	..	..	120,996
No. of corvée on Nile Protection . . . }	1,755,295	..	..	1,754,150	..	..
Money value of above corvée . . . £ . . . }	52,659	..	52,659	52,624	..	52,624
Total cost of earthwork and Nile Protection . . . £ . . . }	..	..	131,988	..	..	173,620

1884—First year of English supervision. Since 1884 the heavy canal work has been done by the corvée and the light by the contractors. Moving the corvée from small canal to small canal is very wasteful.

APPENDIX VI.—DETAILS of EARTHWORK in APPENDIX V.

—	1883.		1884.	
	Cubic Feet.	£.	Cubic Feet.	£.
Summer canals . . .	130,279,000	145,723	84,452,400	140,564
Flood canals . . .	120,158,260	60,000	61,680,200	46,859
Drainage cuts . . .	..	..	..	..
New projects . . .	..	..	27,357,000	17,849
Total . . .	250,437,260	205,723	176,489,600	205,267

—	1885.		1886.	
	Cubic Feet.	£.	Cubic Feet.	£.
Summer canals . . .	26,391,770	48,636	32,087,200	74,321
Flood canals . . .	27,596,933	16,888	33,615,348	28,228
Drainage cuts . . .	5,112,300	6,525	10,943,000	5,125
New projects . . .	12,853,200	7,280	15,514,300	13,222
Total . . .	71,954,203	79,329	92,159,818	120,896

Prices of earthwork vary from 8s. per 1,000 cubic feet to £2 per 1,000 cubic feet, according as it is dry or slimy, when done by hand-labour under contract. The *corvée* clears the slime at a cost of £3 10s. per 1,000 cubic feet. Dredgers excavate the slime at a cost of £1 5s. per 1,000 cubic feet.

**APPENDIX VII.—COST OF CANAL CLEARANCES, and of NILE PROTECTION
PER MILE OF CANAL, and BANK, and PER ACRE IRRIGATED.**

Second Circle of Irrigation.

Years.	Length in Miles.	Area Commanded.	Cost of Clearances and Protection.	Total Cost.	Cost per Mile.	Cost per Acre.
		Acres.	£.	£.	£.	s. d.
1883.						
Summer canals . . .	1,431	1,182,691	145,723	297,686	102	5 0
Flood canals . . .	747		60,000		80	
Drainage cuts . . .	174		0		0	
Nile banks protection .	265		91,963		347	
1884.						
Summer canals . . .	1,431	1,182,691	140,564	201,082	98	3 6
Flood canals . . .	747		46,859		63	
Drainage cuts . . .	174		0		0	
Nile banks protection .	265		13,659		52	
1885.						
Summer canals . . .	1,431	1,182,691	48,636	124,708	34	2 0
Flood canals . . .	747		16,888		23	
Drainage cuts . . .	174		6,525		37	
Nile banks protection .	265		52,659		200	
1886.						
Summer canals . . .	1,431	1,182,691	74,321	160,298	51	3 0
Flood canals . . .	747		28,228		40	
Drainage cuts . . .	174		5,125		29	
Nile banks protection .	265		52,624		200	

From the above it is evident that an additional land tax of 3s. per acre would suffice for the complete abolition of the *corvée*. This tax might be raised to 5s. in Menufieh and southern Garbieh, and lowered to 1s. in northern Garbieh. Lands which now pay a tax of £1 12s. per acre, and are rented at £4 or £5 per acre, and sold at prices ranging between £35 and £70, could easily bear an additional tax of 5s. per acre. Under the present system of *corvée*, all persons who own more than 5 acres pay nothing towards *corvée* work, while those who own less than 5 acres pay £3 per acre per annum towards *corvée* work.

[DISCUSSION.