Mr. Anderson. He had noticed, in traversing the portion of the Delta which the Author considered specially suitable for that mode of irrigation, that nearly all the villages were built on hillocks. It seemed as if the villages, which no doubt had existed from time immemorial, had been purposely placed in such situations as to render basin irrigation possible, and he did not well see how the salt, which now encumbered the land, and in places rested like snow upon the ground, was to be got rid of except by flooding the whole area of the fields at high Nile, letting the water drain through, thus washing out the salts and leaving the deposit of rich mud on the surface. He did not think there was any other method that would restore the land to the fertility which evidently it had at one time enjoyed.

Lieut.-General Rundall. Lieut.-General F. H. RUNDALL said that the same thing had occurred in almost all the deltas in India, especially in the Godavery District, in the neighbourhood of a large lake situated at the water-sink of the Rivers Godavery and Kistna. There the efflorescence on the soil was in large quantities, but as soon as the canals were excavated, fresh water laden with silt was sent down during the flood season when all the lands were flooded, not for any length of time, but periodically, and resulted in the finest crops being afterwards raised on that very soil.

*** The Author, being in Egypt, has not yet had an opportunity of replying to this Discussion.

Correspondence.

General Cotton. General Sir ARTHUR COTTON, K.C.S.I., stated that before he left India he had come to the conclusion that cheap carriage, which could only be obtained by means of water, was of even greater importance there than irrigation; and he felt assured that in Egypt, even though the distances were so small, the water transit was an essential part of the work of improving the Delta. Of the immense capabilities of the Delta he had no doubt, and, indeed, what had already been accomplished by Colonel Scott Moncrieff with such insignificant means, was a proof of that.

Mr. Evans. Mr. C. T. EVANS was predisposed to believe that the basin system advocated by the Author was calculated to prove eventually injurious rather than beneficial to the soil, especially where there was not fall enough to admit of the water flowing off quickly after deposit of the matters held in suspension. The land must, he thought, eventually become water-logged and unproductive. He gathered from the Paper that, under the basin system, the country would be flooded for from one month to two months; the soil would thus be saturated, and in a low-lying flattish country would practically remain so. Moreover, as regarded Lower Egypt, he thought that, owing to the basin system in Upper Egypt, the flood water both arrived too late, and was deficient in the material which was said to confer productiveness. The conditions, therefore, under which basin irrigation would be carried on in Lower, were much less favourable than they were in Upper, Egypt. He was strongly of opinion that an extension of the canal system, accompanied by efficient drainage, was the only safe one to adopt for Lower Egypt. This of course would not succeed without strict administration and regulation, and such, he gathered, did not exist at present, the landowners higher up taking water at will at the expense of those lower down. As regarded navigation, he would do without it, and have light railways or tramways for communication and carriage. Navigation and irrigation were incompatible. Mr. Evans.

Lieutenant-General J. G. FIFE observed that more than thirty years ago he visited the Barrages, and was shown over the works by Mougel Bey, who at that time was engaged in strengthening the talus, or apron, by lowering masses of concrete from boats to the bed of the river, which had been previously dredged. The concrete was in boxes with movable bottoms; these were opened at the river bed, thus allowing the concrete to pour out and adapt itself to the cavity, to be filled before setting. Mougel Bey did not then appear to have any doubt as to the success of the work. On two points only had he some brief remarks to make. In the first place, the Author thought it would be possible to regulate the river floods by admitting them into the basins, and allowing the water afterwards to return to the river to maintain the supply after the flood had passed off. This was a large question, and, without figures showing the capacity of the basins and the levels, it was impossible to come to any conclusion. The difficulty to his mind was to deal with the vast body of water quickly enough; for it was not as if there was a weir across the Nile in Upper Egypt, and the object was merely to divert the stream. Without elevating the river above its natural flood level, an enormous volume of water had to be drawn off. Secondly, without in the least underrating the advantage of reducing the deposit of slime in the canals in Lower Egypt, both to save expense of clearance and to increase the efficiency of those works, he thought that too much Lieut.-General Fife.

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credit was given to the fertilizing effect of the slime, and that it would be found that the grand cause of the deterioration of the soil on the regularly cultivated lands was simply over-cropping, and want of plenty of manure and judicious rotation of crops. Commerce had stimulated production beyond the powers of the soil. In Sind, a province watered by the Indus, and very similar in character to Egypt, the canals had such a velocity—generally over 2 feet per second—that the slime was carried on to the fields, the sand only, as a rule, being deposited in the canal. Yet it was found that after a crop of maize, which sometimes attained a height of 8 to 10 feet, the land had to be left fallow from one year to three years. Rice lands properly irrigated also required to be left fallow, or to have plenty of manure. Rice lands not regularly irrigated, but from their low level completely flooded, were cropped every year, but the crop was an inferior one. Rice in such a situation grew as much from the water as from the soil. The water gradually rose during the inundation period, June to September, and in places attained a depth of 4 or 5 feet; but the rice rose with it and kept its head above water, and was eventually reaped with the aid of boats.

Sir Charles Hartley.

Sir CHARLES A. HARTLEY, K.C.M.G., observed that the Paper was naturally of great interest to him, as he had ascended the Nile in sailing vessels from the Damietta mouth to Assouan in the winter of 1860–61, and in the spring of 1877 had been invited by the Ex-Viceroy of Egypt, Ismail Pasha, to visit the Barrage, in order to report to His Highness on the projects of Mr. (now Sir John) Fowler and Mr. Gatget (a distinguished engineer, representing the Fives Lille Company in Egypt), for utilizing the Barrages to the best advantage. As this great work was the most prominent feature in the Paper, he would quote the following passages from his report to the Ex-Khedive in June 1877, three months after he had visited the ground in company with Mr. Gatget and Ali Pasha Mabarah, the Minister of Public Works at that period:—

"After a close study of the subject in all its bearings, I agree with Mr. Fowler and Mr. Gatget in their opinion. Firstly, that it is more desirable to utilize the Barrage with its bridges, locks, canals, &c., than to resort to other proposed solutions, such as the more costly expedients of establishing a 'grand canal de dérivation' high enough up the Nile to bring its waters at the low-water season to the required level at the head of the Delta; of constructing an entirely new barrage at some point between Cairo and the existing work, or of gaining the same end by means of pumping only; and, Secondly, that, the failure of the Barrage is due to

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defective foundations and not to any violation of general principles in the original design. Disbelieving in the efficacy of any means of effectually repairing the foundations, Mr. Fowler and Mr. Gatget recommended the construction, across both arms of the river close to the Barrage, of a wall of rubble masonry founded at a great depth, and designed so as to remove all future anxiety regarding the effects of infiltrations either through or below the masonry, or rubble, of the existing work. There is, however, a notable difference in some respects in the two projects. Mr. Fowler proposes to complete the sluices of the existing Barrage, to construct a new set of sluices on deep foundations immediately *below* the down-stream edge of the present foundations, and to arrest the erosion of the river bed below the Barrage by protective works of an important and adequate character. As, in Mr. Fowler's opinion, it would be inexpedient to expose the foundations of the present work to a greater chance of undermining than they have hitherto encountered, the future head above the old works would be limited to $1\frac{1}{2}$ metre, and, a lower curtain wall being constructed, there would be no danger of the existing foundations being undermined. The new sluices would be founded on a continuous solid wall 8 metres thick, carried down to a depth of 18 metres below low Nile—deep enough to avoid all risk of sand being carried under it by the difference of hydraulic pressure on its front and rear sides, and to prevent undermining by the severe action of the under current produced by falling water. The river bed below the Barrage would be covered with a broad mass of rubble, incorporated with which would be two lines of heavy béton blocks. The top surface of these defensive works would be kept 8 metres below low Nile in order to obtain an efficient water cushion for the falling water. Immediately in front of the wall would be a line of béton blocks of sufficient weight to resist removal by the under current, and to form with the rubble a solid abutment to the whole structure. It has already been observed that the submerged foundations of the Barrage are of less weight than the head of water it was intended to bear when it was first designed, and that, therefore, the bed of the river being exceedingly mobile and porous, grave doubts might have arisen as to the ultimate stability of the structure, even supposing the béton had been sound throughout. In considering the question of head, it should be borne in mind that the irrigation canals, when the Barrage is finished, will withdraw 230 cubic metres per second or two-thirds of the minimum low-water flow of the Nile, and that consequently the present low-water level below the Barrage, when

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the maximum contemplated head of water has been obtained, will be considerably lowered, so that, including the height of water flowing over the top of the sluices, the difference in level above and below the gates would occasionally be as much as 6 metres. Now, the weight of 6 metres of water being equal to 5·64 cubic metres of submerged concrete, and allowing a margin of safety of only 50 per cent., the foundations of the new work should be founded, irrespective of other considerations, at a depth of 8½ metres, to guard against all danger of the apron being blown up by the upward pressure of a possible head of 6 metres above the sluices. Unfortunately, however, another element, more dangerous than that of mere statical pressure, must be taken into account in dealing with the 'fine running sand' of which the bed of the Nile at this locality is said to be composed to an unknown depth, and that is the percolation of water underneath the foundations, by the action of which, if the foundations are not deep enough, the whole work is liable to be slowly but surely undermined. To check this percolation, the best plan, in my opinion, is to sink the foundations to such a depth as would cause the substratum to be less permeable by the pressure upon it of a massive wall of great weight, as proposed by Mr. Fowler. Mr. Gatget's project is to construct, at the distance of 40 metres *above* the old works a strengthening wall founded at a depth of 22 metres below zero—a depth which Mr. Gatget considers necessary in order to reduce the leakage under the wall to such an insignificant quantity as to be practically harmless. On this wall would be built sluices of sufficient solidity to resist the pressure of a maximum head of 5·80 metres of water. The space between the old and new works would be filled up by widening out the concrete and masonry of the existing platforms. It is incumbent on me to refer to the unsatisfactory condition of the *régime* of the Nile between Cairo and the Barrage, and especially of the reaches immediately above the latter. When I descended the river from Cairo on the 9th April in your Highness's steamer, the level of the water at the Rosetta Barrage, the sluices of which were closed, stood at 2·50 metres above zero on the upper side of the sluice gates, and at 1·75 metre above zero below them. The head of 1·75 metre was employed in feeding the central canal, and in scouring the Damietta branch, the sluices of which were open—otherwise the east channel below the Barrage, as well as above it, would have been completely dry at the then low-water stage of the river. This circumstance, and the fact that the large pool facing the upper side of the Damietta Barrage, would then have been a *cul de* *sac*, except for the artificial current flowing from the Rosetta branch along the revetment wall which connects the two Barrages, at once convinced me, irrespective of the evident signs of the recent erosion of the left bank of the main stream, that the natural tendency of the river current is forcibly to direct itself more and more to the west. This, of course, is done at the expense of the Damietta branch as soon as the Rosetta sluices are lifted; and if the river is left much longer without control, the Damietta Barrage is liable to be left high and dry and the Rosetta Barrage outflanked or destroyed at no distant day. It is, therefore, urgently necessary not only to complete both Barrages according to the original design, but to regulate the flow of the river for a long distance up stream as well; for although the acquisition of the desired head of water would ensure a perfect control over the quantity flowing down each branch at low Nile, there would be no such control at high Nile, when all the sluices would be open. Consequently the construction of extension and substantial guiding works for some miles above the Barrage is absolutely necessary, to protect the latter against the dangerous effects of an uncontrolled current when the sluices are lifted." Sir Charles Hartley.

The Author stated that the severe action below the Barrage when a gate was lowered to its full extent, was found to be due to iron gratings or "windows" in the foundation, and not, as it had been supposed by the writers of the reports on the Barrage, to a honeycombed foundation. Sir C. Hartley now heard of these *open* gratings for the first time. Their existence was never mentioned by Mr. Gatget and the Minister of Public Works when they accompanied him to the Barrage; and in all his communications with Sir John Fowler and his staff, it was taken for granted that the alleged inability of the structure to withstand uninjured a greater head of water than 2 metres was solely due to the porous nature and insufficient depth of the foundations. This view was also confirmed as lately as 1883 by the Public Works Ministry, who then asserted that, owing to the defective foundations, any attempt to hold up the water beyond what was necessary to prevent the Nile from flowing altogether in the Rosetta branch, and leaving the Damietta dry, would lead to disaster. In describing the Rosetta Barrage, the Author stated that the left half of the platform was laid on loose sand, and the right half on loose stone, and that the whole barrier was practically watertight, owing to the excellent cementing properties of the slime deposit of the river. He further declared that all the water that escaped through the Barrage found its way through the iron gratings and not

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through fissures in the concrete, as had been formerly supposed. This new and favourable view of the stanchness of the foundations induced Colonel Scott Moncrieff, when he took the direction of public works in 1884, to disregard the discouraging predictions of his predecessors, as well as the universal feeling of distrust which followed the giving way of some of the work when it was first tested, soon after its completion in 1862, and to try the bold experiment of increasing the head of water against the Rosetta dam to 10 feet, and against the Damietta dam to $5\frac{1}{2}$ feet. By way of precaution, however, he closed the gratings, and added considerably to the width of the rubble bank immediately in rear of the submerged platforms, in the manner described by the Author, so as to oppose more weight to the proposed augmented horizontal thrust against the structure. The result of this experiment had been entirely successful, and when in Egypt two years ago, and also elsewhere since that time, he had heard many distinguished engineers (French and Italian, as well as English) who had made the question of the Barrage a special study, express their warm admiration of Colonel Scott Moncrieff's famous achievement in adding so greatly to the utility of the Barrage in so short a time and for so little money. It now remained to be seen what effect would be produced on the work when the desired head of 5 metres, in two drops of say $2\frac{1}{2}$ metres each, had been obtained. For his own part, he would have preferred the adoption of a plan which, while retaining the principle of a double drop, would have provided for the establishment of new foundations for a second or supplementary dam below the existing one, founded on a solid wall of masonry at such a depth as would have made the structure *absolutely safe for all time.* Nor, in his opinion, would the comparatively large expenditure required for such a work be difficult to justify, for not only did the successful irrigation of the Delta at low Nile depend on the absolute stability of the structure, but the retention of the head of water at the height originally intended was undoubtedly the best auxiliary for distributing the waters of the Nile in suitable proportions through its two deltaic branches. When the Barrage was designed by the French engineer Mougel Bey, in 1843, the chief flow was through the Damietta branch; and even in 1855, according to Linant Bey's Hydrographic Chart of Lower Egypt, the volume of water discharged in flood by the Rosetta and Damietta branches was 4,665 and 4,287 cubic metres per second respectively at high Nile. At the present time, however, according to the Author, the Rosetta had nearly twice the flood supply of the Damietta branch. This serious change in so short a time, in the relative discharges of the two branches, was very significant of what might be expected to occur at the apex of the Delta, if efficient means were not speedily taken to regulate the volume of the main stream in such a way as to assure a constant and sufficient flow through the Damietta branch, the navigable channel of which, according to his information, had lately very sensibly deteriorated both in depth and width. In his Paper on "The River Nile,"[1] Mr. Baker gave a valuable tabular statement of the average discharge of water and solids per month, and in this Table it was specially worthy of notice: first, that in August the Nile conveyed three hundred times more solids in suspension than in May, although during the former month the volume of water discharged was only ten times greater than in May, the weight of solids in suspension to the weight of water being then $\frac{1}{21,000}$, whilst in August it rose to $\frac{1}{674}$; secondly, that in August, although the volume of water discharged was only one-quarter less than in October, the suspended sedimentary matter was three times greater in August (when the weight of sediment attained its maximum of 23,100,000 tons) than in October, when the discharge of water was greatest, although the solids in suspension had then decreased to 7,600,000 tons, the proportions of sediment to water being $\frac{1}{674}$ and $\frac{1}{2,640}$ respectively. This investigation afforded strong corroborative evidence of the importance of the Author's remark that in October the Nile water was diluted with the clear basin water of Upper Egypt, and it might be added of the Upper Nile, and completely confirmed his own experience respecting similar phenomena on the Lower Danube. As 300 cubic metres per second were already utilized in irrigating 1,155,000 acres in the provinces of Menufieh and Garbieh, and as the minimum flow of the Nile, 400 cubic metres per second, would be needed to irrigate 1,540,000 acres at low water when the Barrage was completed, the east and west provinces, which had an area of 3,960,000 acres (the total cultivable area of the whole Delta being 5,500,000 acres, or 8,600 square miles), must depend on the flood waters alone for irrigation. Consequently, as the Author had pointed out, the reclamation of Lower Egypt or the Delta by summer irrigation was impossible. The value of the Barrage, therefore, in utilizing the summer supply in the two central provinces was small in comparison with the full utilization of the flood-waters on the improved system of distribution introduced, and already so successfully practised, by Colonel Scott Moncrieff and his staff. This remark would have

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[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 373.

Sir Charles Hartley. greater force when it was remembered that the flood supply of the Nile, during the five months of August to December inclusive (when the soluble constituents had the highest fertilizing power), carried in suspension 47,000,000 cubic metres of solid matter possessing extraordinarily rich fertilizing properties, as compared with 2,500,000 cubic metres of inferior fertilizing ingredients during the seven months from January to July inclusive; the proportion of solids to the weight of water being $\frac{1}{1,560}$ in the first period, and $\frac{1}{8,270}$ in the second period, during the greater part of which the Barrage would be closed.

Thanks to British administration, and to the enlightened zeal of Nubar Pasha, the abolition of the corvée had at last been proclaimed throughout the land of Egypt. That cruel system, which kept alive discontent among the fellahs by compelling them to leave their own fields to toil for the State, was in full force in 1862, at which period he was informed on the ground, by an official high in office, that an average of one hundred and fifty thousand men were annually employed during four months of the year in removing silt from the canals, repairing the river banks, and in constructing new works. So lately as 1884 also, as stated by Mr. Cotard,[1] more than 10,000,000 cubic metres of silt were lifted annually from the canals in Lower Egypt alone, a work which required the calling out of one hundred thousand men during several months. With the system of hired labour now so happily introduced, and the recent greatly improved water distribution in Egypt, whereby according to the Author the silt clearances had already been reduced to one-fifth of what they were, these great reforms, together with the abolition of the corvée, which could only be accomplished by enormously decreasing the labour formerly required for the periodical cleansing of the canals, would be an immense boon to the cultivators of the poorer class, and would unquestionably have the effect of rendering the onerous land-tax of the Government less heavy for them to bear. The question of making the principal canals navigable, in order to convey the produce of the fields cheaply to market, was only alluded to incidentally by the Author, who inclined to the idea that light tramways would pay better, as "the work of combining navigation, drainage and irrigation, with their conflicting interests, is so difficult and costly." Without attempting to contest this view, he would merely remark that, wherever new canals

[1] Le Nil et l'Égypte, par M. Charles Cotard, Siège de la Société d'Études du Nil, 46 rue Cambon, Paris, 1884.

were made or old ones improved, it appeared to him very desirable, as a rule, that they should leave the river at right-angles and never obliquely in a down-stream direction, as in the case of the Behera and Charkieh canals immediately above the Barrage. Sir Charles Hartley.

The navigation of the Nile proper was a far larger question, and although the subject of river navigation hardly came within the scope of the Paper, he might perhaps be allowed to offer a few remarks on this interesting topic, as well as on the chief characteristics of the Nile, as compared with three other rivers of greater importance as navigable streams.

RELATIVE CHARACTERISTICS of the NILE, the GANGES, the MISSISSIPPI, and the DANUBE.

—	Length in Miles.	Drainage Area in Square Miles.	Annual Rainfall in Cubic Miles.	Mean Annual Discharge in Cubic Miles.	Mean Ratio.	Mean Weight of Dry Sediment to Weight of Water.
Nile . . .	3,300	1,293,000	892·1	22·7	39·3	$\frac{1}{1,900}$
Ganges . . .	1,680	588,000	548·8	43·2	12·7	..
Mississippi . .	4,190	1,244,000	673·0	132·0	5·0	$\frac{1}{1,500}$
Danube . . .	1,750	316,000	198·0	44·3	4·5	$\frac{1}{3,060}$

As the central and lower parts of the Nile flowed through an exceptionally dry and sandy region, it discharged, as shown on the Table, only $\frac{1}{39}$ of the annual rainfall on its catchment-basin, and as regarded ratio of rainfall to discharge, compared with other rivers, it was three, eight, and nine times greater than the Ganges, Mississippi, and Danube respectively. Again, although the Nile had about the same drainage area as the Mississippi, its annual rainfall was 30 per cent. greater, whilst its annual discharge was six times less than that of the "great father of waters." Compared with the Danube, the annual discharge of the latter was double that of the Nile, although the annual rainfall of the Nile basin was four and a half times that of the Danube. The perennial flow of the Nile was due to the magnificent lakes of Central Africa, which lay at its source; while its annual inundation was caused by the flooding of the Atbara and Blue Nile during the rainy season. These two tributaries (although almost dried up from the end of October to the middle of May, when mountainous Abyssinia was as

Sir Charles Hartley. rainless as Egypt) were mighty streams from the beginning of June to the end of September, and the undoubted origin of the periodical inundations, the unfailing deposits, and the wonderful fertility of Lower Egypt. He would also cite some further examples, which proved that the Nile was essentially an anomalous river. When other great streams in Europe, Asia, and America were at their lowest, the Nile was in high flood, for it continued rising till October, when it reached its maximum height. Again, unlike every other river in the world, it rose every year, with marvellous regularity as to time and fixity of volume, and flowed for the last 1,600 miles of its course from the mouth of the Atbara (200 miles below Khartoum) to the sea, without receiving a single tributary. Finally, owing partly to the large deposit of alluvion on the land before the fluvial current reached the sea, and partly to the strong littoral currents which swept away the remaining deposits to the deeper parts of the Mediterranean, "The Delta," to quote the words of an eminent geologist, "now gains little or nothing on the sea, and the coast is changed but very slightly from what it was three thousand years ago."[1] The navigable channel of the Nile, from Assouan to Cairo, was deep enough all the year round for vessels drawing 5 feet, and from August to the end of January for vessels of 8 feet draught. In this respect, therefore, the Nile in its untrained condition from the first cataract to Cairo, 590 miles, was as good as that of the untrained Danube from Ibraila to the Iron Gates, a distance, however, of but 370 miles; whilst it compared very favourably with many artificially trained European rivers, where great expense had been incurred to obtain even a less depth than 5 feet over a considerably shorter distance. The existence of strong currents off the Delta seaboard would have been highly advantageous to the maintenance of deep water at either the Rosetta or Damietta mouth, where the depths were now only from 5 to 8 feet, if parallel piers had been constructed at either entrance on the system which had been so successfully carried out at the Sulina mouth of the Danube and at the South Pass of the Mississippi. So far as he could learn, there had never been a serious project having this object in view, and the facts that the construction of the Barrage itself manifestly created a permanent and very grave obstacle to the navigation; that the railway bridges below Cairo were only open once a day to shipping; and that heavy taxes were imposed on trading vessels,

[1] "Geology: Chemical, Physical, and Stratigraphical." By Joseph Prestwich. Vol. i. p. 86. 1886.

as was the case when he was last in Egypt, amply demonstrated that the idea of executing anything like a comprehensive project for the improvement of the navigable channel of the Nile, had never been seriously entertained by the Egyptian Government. In other words, that Egypt being emphatically an agricultural country, the improvement for navigable purposes of its great natural highway had always been considered entirely subordinate to the more pressing demands for efficacious and economical appliances for ensuring the due irrigation of the land at all seasons. Sir Charles Hartley.

Major-General P. P. L. O'CONNELL, R.E., remarked that whereas the operations included under the general term "irrigation" embraced the providing periodically of a fresh and well manured soil, as well as the watering of that soil either continuously or at intervals during the growth of a crop, the Upper Egyptian system was almost confined in winter to the first operations of providing a new well manured and saturated soil. He said almost, not entirely, confined, as probably there might be some subsequent watering. It would appear that of late years a system of summer irrigation had gradually been improved, if not absolutely perfected, in Lower Egypt, which provided the land with as much water as it needed, but gave it little or no fresh soil or manure. From the remarks recorded at the end of the Paper, it would almost seem as if the Author thought the deterioration of the soil, in Lower Egypt of the present day, was due to this improved summer irrigation. Doubtless he was quite correct in asserting that Lower Egypt wanted the slime of the Nile. But could this not be provided by opening out large canals from the river, and thus forming a flood-season system to be worked either together with or in continuation of the summer system? It was much to be regretted that this question had been overlooked for so long a time. It presented difficulties, which could probably be overcome only by skilful hydraulic engineers thoroughly acquainted with Egypt and the Egyptian system, but these would require time and money to work out a remunerative and otherwise satisfactory plan. In order to show the necessity for a special study of this great problem, he would draw attention to an existing successful system of irrigation, in which the original natural features were nearly similar to those of Egypt and the Lower Nile, but which could not be exactly copied, owing to the great differences in the present works of art in the two countries. He meant the system on which nearly the whole of Tanjore and a portion of the Trichinopoly district of Southern India were irrigated. In the Indian system the water was supplied by a river which divided Major-General O'Connell.

Major-General O'Connell. into two branches at the head of the Delta, distant about 80 miles in a direct line from the sea, the left-hand branch being about 800 yards in width, and flowing over a bed having a lower level than that of the right-hand branch; so much so that a weir had to be constructed across the left-hand branch, in order to prevent the right-hand branch being silted up, and deprived of the water required for the irrigation of a large area of land. The Nile also divided itself into two branches, of which the left-hand one flowed over a lower bed than the right-hand one, but the artificial treatment of the two rivers had been very different. In the Nile, weirs had been run across both branches, and a main irrigation canal was carried between them in order to irrigate the land between the two branches. In the Tanjore and Trichinopoly system, the water was distributed not through a small canal, but the whole of the right-hand branch of the river, also about 800 yards in width, carried off the water for irrigation; and, except in heavy floods, the whole was distributed by a river system, the first branch being divided and sub-divided so that the water was spread over a large area, and the surplus entered the sea at many points along a length of 100 miles of coast. The earliest flood of the irrigation season was generally a small one, and the cultivators desired that it might be preceded by very dry hot weather, in order that the ground might have its surface cracked all over, and thus be prepared for the reception of the sediment brought down by the river, which contained vegetable as well as mineral matter. In heavy floods much of the water brought down the right or irrigation branch of the river, was returned to the left or drainage branch at about 15 miles below the primary bifurcation, over a large waste weir locally termed the "Grand Anicut." It would thus be seen that the Tanjore system combined the advantages of the Upper Egyptian system with that of Lower Egypt. One something like it, without being an actual copy, might perhaps be introduced in the Delta of the Nile. With respect to the question of the stability of the Nile Barrage, it would not be necessary to repeat the description of the works themselves, given in the Paper; but it might be useful as well as interesting to consider the mode in which a portion of the work was injured. The description of the regulation of the Barrage previous to 1884, and the resulting accident, seemed to be a perfectly correct statement on the part of the Egyptian foremen. Among the causes of the injury sustained by the Barrage should be mentioned the rapid current, not merely through the last openings, but along the face of the work from east to west. This current must have carried a considerable

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portion of the water flowing down the eastern half of the Rosetta branch over to the western side, and in so doing it must have removed a good deal of surface-silt and fine sand also from the bed in front of the Barrage, thus increasing the flow through the bed under the work from south to north; and as a greater scour was at the same time produced by the action of the water flowing on to the bed on the northern or down-stream side of the work, the velocity with which the water flowed through the bed was probably sufficient to remove material from under the flooring. When all the openings had been closed, a healing process would set in. There would be no more scouring, but on the contrary, a deposition of silt would take place, plastering over, so to speak, the wounds previously inflicted on the bed above the Barrage, and checking the under-current. How slight a current would suffice to remove portions of the bed, first on the down-stream side of the work and then beneath it, until hollows were formed under the solid masonry, might easily be conceived. It had been described by Mr. B. Baker [1] in the following terms:—"Borings to a depth of 100 feet show that the soil is light stuff which melts almost like sugar when in contact with water; so the present critical state of affairs requires no further demonstration." Possibly the subsoil might be of a similar character to a much greater depth, even so far from the sea as the head of the Delta; but the fact that the Barrage was still standing showed, that when the distance between the points at which the water forming the subsoil current entered and issued from the bed was sufficiently great, that subsoil, subjected as it was to the pressure of the superincumbent masonry, was very little disturbed by the water flowing slowly through it. Experience in this case, as in others, also showed that when the distance, between the points at which the water forming the under-current entered and issued from the bed, bore too small a ratio to the head of water above the work, the subsoil would be disturbed, and the work would in time be undermined. The stability of the work would, in his opinion, be increased by covering the bed of the Nile above the Barrage. This covering might be laid at a lower level than the crest of the platform on which the bridge stood. Its depth need not exceed 2 feet; its surface might be depressed somewhat on its up-stream side. It would not be required, perhaps, along more than one-third of the length of the work, if placed in front of the openings which were the last to be closed; but all details might safely be left to be settled by the

[1] Minutes of Proceedings Inst. C.E. vol. lx. p. 374.

Major-General O'Connell. experienced officers now in charge of the works. He should only add that the views which he had here expressed were not merely conjectural. They were the results of observations made, it was true, on rivers whose beds contained coarser sand than that of the Nile as well as fine mud. On the latter river it would probably not be easy to make similar observations, as its bed both above and below the Barrage was, he supposed, nearly all covered with water even in the driest season. It was, of course, necessary to the stability of weirs across rivers, with beds of fine material to very great depths, that the surfaces of such beds should be kept as clear as possible of shoals and islands in the vicinity of the work. In a neglected river of this kind, islands were apt to be formed, dividing the main stream into two or more parts. These streams rejoining a little above the work produced cross currents scouring out the bed, undermining solid masonry, and sinking boulders beneath the fine material. Where a proper department was maintained, none of these evils need be feared. The training of rivers was an interesting work, and, if kept steadily up, by no means difficult in any country provided with a government both willing and free to provide the necessary funds.

*** The Author, being in Egypt, has not yet had an opportunity of replying to the correspondence.