The Author.

With regard to Mr. J. S. Wilson's query as to whether the regulation had been adopted that the masonry pressure on the face should exceed the hydrostatic pressure at any point, Dr. Phillips, who had dealt with this part of the original design, had written that the masonry pressure, neglecting uplift, at the upstream toe of the dam at R.L. 387 metres in the pierced section, when the upstream level of the water was 420·70 and the downstream was dry, came to 2·31 kilograms per square centimetre (2·16 tons per square foot), whereas the water-pressure was 3·37 kilograms per square centimetre (3·08 tons per square foot), that was, the masonry-pressure was roughly two-thirds of the water-pressure. That was what Dr. Phillips had expected, since in allowing for uplift he had allowed for water-pressure starting from full head upstream and falling to full head downstream, and acting over two-thirds of the area of the horizontal section. As the resultant pressure came a little inside the middle third, the masonry-pressure was a little more than two-thirds of the water-pressure.

Correspondence.

Mr. Dare.

Mr. H. H. Dare observed that, taking into account the climatic conditions, the difficulties of unwatering, and the limited period available each year for working in the river-channel, the successful completion of this great work in a reasonable time was a matter for congratulation to all concerned. The proportion of mortar in the Sennar dam, 40 per cent., corresponded with that in the original Assuan dam, in which it was stated[1] to have "varied between 35 per cent. and 42 per cent." Did the size of the granite hearting stone used at Sennar correspond also with that used at Assuan? Even allowing for the great increase in the cost of all construction work since 1902, the comparison of the cost per acre-foot of water stored was somewhat striking, namely :—

	Capacity: acre-feet.	Cost per acre-foot.
Assuan Dam (original height)[2]	863,453	£2·7
Sennar Dam	515,612	£11·1

The cost, per acre-foot of water stored, of four large irrigation

[1] Minutes of Proceedings Inst. C.E., vol. clii, p. 89.

[2] *Ibid.*, p. 104.

Mr. Dare. dams in New South Wales, with which Mr. Dare was connected, was estimated as :—

	Progress	Capacity: acre-feet.	Cost per acre foot.
No. 1.	Practically completed	771,641	£2·2
No. 2.	In progress	2,000,000	£2·3
No. 3.	Preliminary designs prepared . .	273,694	£4·9
No. 4.	,, ,, ,, . .	520,000	£4·6

In the case of No. 2 the original proposal had been for a dam to store 1,100,000 acre-feet of water; and the structure, which was partly an embankment with a concrete core, and partly a concrete overfall section, had been commenced upon that basis; but in view of later developments the question of increasing the capacity to the larger figure given above was now receiving consideration. Nos. 1, 3, and 4 were concrete structures. In each case a flood of considerable magnitude had to be provided for, but as no unusual amount of silt was carried, the provision of sluices was not necessary to anything like the same extent as in the Nile dams. This factor had, no doubt, an important bearing upon the cost, but on the other hand, the lowest wage paid to workmen engaged upon the construction of dams in New South Wales was, at the present time, 17*s.* 0*d.* per day of 8 hours. No adequate comparison could, of course, be made of the cost of works carried out under such different conditions, but it would be of interest to know whether the full cost of the Sennar dam, as well as that of the main and reticulation channels, was to be charged to the irrigation area, and if so, what were the charges per acre per annum for rent (or purchase) of land, and for the supply of water for irrigation.

Dr. Hurst. Dr. H. E. Hurst congratulated the Author, the contractors, and the staff employed, on having brought to a successful conclusion the work on the Sennar dam and the canalization of the Sudan Gezira, the difficulties of which could only be properly appreciated by those familiar with the conditions. It might, however, be mentioned that during three of the principal working-months the average maximum temperature was 106° F., and the mean temperature 88° F. He had been consulted when the designs were being made as to what the discharge of the sluices was likely to be. The only information then available was from Assuan, where the sluices were of similar design, but where the conditions of upstream and downstream level were different. At that time it was not possible to make a detailed forecast of the discharge of the Sennar sluices under all conditions, but the information sufficed to decide how many sluices were necessary to carry the maximum discharge. Since that time further work had been done on the discharge of the

Dr. Hurst.

Assuan sluices,[1] and in particular it had been shown that a model could be used to determine the discharge of a large sluice. At the Author's request a model of a Sennar sluice had been constructed, and its discharge had been measured over a wide range of conditions. This model was of brass, and to a scale of 1/50. The general results showed that there were two modes of discharge, with a region of transition between them. In one the discharge depended only on the upstream level and was the same as the free discharge into air. It was represented by $Q = cA\sqrt{2g(H-F)}$, where Q was the discharge, c a constant, A the area of sluice-opening, H the level upstream above the sill of the sluice, and F a constant, for a particular opening, which, except in the case of a fully-open sluice, was about 0·8 times the height of the opening. This mode of flow occurred with the lower downstream levels, but as the downstream level was raised, there came a point, depending on the upstream level and the opening, when the discharge was affected by the downstream level. The formula then became $Q = cA\sqrt{2g(H-h)}$, where h was the downstream level above the sill. At first c varied with the downstream level. This was the transition region. Ultimately, as the downstream level rose, c became steady and usually had the same value as in the first equation. The second mode of flow was then properly established. The model experiments had been used to predict the discharge of the full-scale sluice by means of the relation $Q = n^{2 \cdot 5}q$, where Q was the discharge of the actual sluice, q the discharge of its model, and n the ratio of the linear dimensions of sluice and model. The regulation of the Sennar reservoir was being based upon these results, and so far there had been good agreement between the discharge of the Blue Nile as determined from the sluices, and as measured by current-meters downstream of the dam. Cases could probably be devised in which a sluice and its model would behave differently, but it was clear that in general models would give, cheaply and quickly, results which could only be obtained otherwise by a considerable expenditure of time and money. With regard to the calculations of uplift due to the penetration of water into the masonry, which were mentioned in the Paper, he would like to suggest that for future reference the assumptions upon which these were based should be recorded.

Mr. Lacey.

Mr. J. M. Lacey asked whether it was proposed to grow the crops in rotation on the area of 300,000 acres which was being irrigated at present. The soil was stated to be a very hard clay

[1] Minutes of Proceedings Inst. C. E., vol. ccxviii (1924), pp. 72 and 113.

Mr. Lacey. known as black cotton soil (loess). What was the depth of that soil, and what formation underlay it? Was there any possibility of the area becoming waterlogged through constant irrigation, or in time rendered unfit for irrigation, owing to a comparatively small depth of black cotton soil being underlain by an impermeable rock? Sections FF and GG, Figs. 4, Plate 2, showed the black cotton soil to be only about 10 feet in depth, overlying conglomerate. The Author stated that hitherto millet had been the only crop grown on the area, and that the crop was precarious, because the tropical rains on which it was dependent were extremely variable: some reference to the seasons and rainfall of the locality seemed desirable, and it would be interesting to know the seasons into which the year was divided, and the mean monthly rainfalls. The Author stated that the heaviest rains occurred in July and August, and the dry period was between October and July. Was the millet sown after the tropical rains, so that it derived the necessary moisture for its growth from the water retained in the clay soil? The Author stated that pumping experiments made by the Sudan Government showed that cotton could be grown on the area during the flood season of the Blue Nile, although in Egypt climatic conditions were such that cotton must be planted in March; and by planting on the rising flood of the Blue Nile in July, the cotton on the Gezira plain was assured of an ample supply of water, except towards the end of the cultivating season, in February and March. It would be interesting to know the season and period of the cotton-crop in the Anglo-Egyptian Sudan; the number of waterings; and the total depth of irrigation plus rainfall required to bring a cotton-crop to maturity, from seed time to harvest. Did the seasons and periods of the maize crop, and the lubia or fodder crops correspond with that of cotton? *Fig. 6* showed that the canal supplied water for irrigation from the 15th July to the 15th April, but it was stated that crops were at maturity in most years at the end of March. The irrigation period would therefore be about 240 days. Had any estimate been made of the saving that would have accrued if the dam had been built with homra or surkhi mortar? Of the rubble masonry in the dam, 54,860 cubic metres had been built with a mortar compounded of 3 parts of burnt clay to 2 of lime; a less quantity of burnt clay, and an addition of clean sand, would reduce the tendency of the mortar to shrink and increase the resistance to crushing. In India a mortar composed of 1 part of pure lime, burnt and slaked, 1 part of surkhi and 1 part of clean sharp sand gave excellent results, if well ground, screened, and mixed. In the case of the Assuan dam Sir Maurice Fitzmaurice

Mr. Lacey. had stated that a mortar composed of 3 parts of burnt clay and 2 of lime with 10 per cent. admixture of sand was excellent and much more watertight than a 4-to-1 cement mortar, if carefully ground, screened, and mixed. The tensile strength of the mortar after 28 days was 160 lbs. per square inch, the lime being a pure calcium carbonate. The reasons given by Sir Maurice why it had not been used on the Assuan dam were that the plant required for its manufacture to keep pace with the contract rate of construction would have been enormous, and that all coal had to be imported from England; consequently English Portland cement had been used. The difficulties of plant and fuel did not appear to have existed at Sennar.

Mr. Strange. Mr. W. L. STRANGE observed that the Paper was practically confined to a description of the construction of the dam of the most recent large irrigation scheme on the Nile. Despite the intense heat and the remote situation, of the works, they had been carried out expeditiously, almost entirely by native labour, and their successful completion within the contract time reflected the greatest credit on those responsible for their execution. The difficulty of laying the foundations of such an immense work at a considerable depth below the surface of a large river in constant flow was, of course, very great, but fortunately it had not been increased by any serious accident. The only delay had been due to financial, not constructional, obstacles; in fact, the presence of the central island in the river-bed had been of great utility, and full advantage had been taken of it. From the general point of view the chief matter of importance was the opposition of Egypt to the construction of the scheme, on the ground that it would deprive existing lower works of the supply to which they were entitled by long user. This opposition had been over-ruled by the British Government in connection with their orders passed after the murder of the Sirdar, Sir Lee Stack. The decision was considered harsh by those ignorant of the actual conditions. The principal of these, as pointed out by the Author, was that the Sennar reservoir impounded only flood water, which would otherwise be discharged unutilized into the sea, while the fair-weather flow would not be interfered with. There was, however, another consideration to be taken into account. From the bed of the extensive reservoir and from the large irrigated area a very considerable quantity of water would be returned by seepage to the Blue Nile, and would thus pass down to Egypt, at a time when an increased fair-weather flow would be of great utility to its irrigation works. Thus the construction of the Gezira scheme would not be detrimental, but on the contrary advantageous, to these works.

Mr. Strange The proposed large schemes at Gebel Aulia on the White Nile, and at Lake Tsana, the source of the Blue Nile, would similarly benefit Egypt. That this was not merely a theory but a fact was proved by experience in India, and the most important instance of that had occurred on the Indus. When great extensions of monsoon irrigation took place in the Punjab upstream, it was at first feared that the increased abstraction of water thus entailed would reduce the irrigating capacity of Sind downstream. The opposite had, however, actually happened, and the cold-weather supply of the lower Indus had since increased. He presumed that gaugings of the Blue Nile below the Sennar dam had been taken; if they were continued, they would show the effect of the construction of that work on the fair-weather flow.

The Author. The AUTHOR, in reply to the Correspondence, stated that the size of the granite hearting was the same as at Assuan, the maximum stone being the largest a man could carry.

The Sennar dam was primarily a diversion weir to raise the water in the river to such a level that it would run into the main canal. It also stored some water. According to Mr. H. T. Cory, of the Nile Projects Commission, only 10 per cent. of the expenditure on the structure should be charged to storage. This would reduce the cost per acre-foot to £1·1. According to Sir Murdoch MacDonald's Paper[1] on the original Assuan dam, completed in 1902, its capacity was 980,000,000 cubic metres and the total cost £E.3,050,000. This represented 796,000 acre-feet and a cost per acre-foot of £3·9 (£E.1=£1 0*s.* 6*d.*). In actual size of structure this dam and that at Sennar were very similar. The cost of the latter having been £E.5,600,000, it would be evident that it was 83 per cent. more expensive. It should be remembered, however, that Sennar was a much more inaccessible place than Assuan: a large part of the labourers had to be transported more than 1,000 miles and back again every year.

The whole of the expenditure on the Sennar dam and the canals was charged to the irrigation area. The Sudan Government had built the dam and excavated canals to bring water within 1,300 metres of any point on the fields. From these a company called the Sudan Plantations Syndicate dug the field channels and made all the other arrangements with the native cultivators, including supply of seed, advances of money, mechanical ploughing, supervision, and ginning and marketing of the cotton. After deducting the actual cost of ginning and

[1] Minutes of Proceedings Inst. C.E., vol. cxciv (1913), p. 249.

marketing, the proceeds of the sale of the cotton crop were divided in the following manner: 35 per cent. to the Government, 25 per cent. to the Sudan Plantations Syndicate, and 40 per cent. to the cultivators. Out of the 35 per cent. the Government had to meet interest and sinking-fund on the loan which had been raised to carry out the dam and Government canals. The Author.

The Paper was not intended to deal in detail with the canals.

The depth of the black cotton soil, which was a stiff loam containing 55 to 60 per cent. of clay, ranged from 5 to 20 metres. It overlay sand. There was no conglomerate or rock, such as occurred at the site of the dam. The subsoil water-level was at a great depth below the ground—up to 40 metres. Therefore, there seemed to be no fear that it could ever rise to such a level as to cause water-logging of the soil. Space had been left for the digging of open drains for the removal of surplus surface water, should they be found necessary in the future. Up to the present, the agriculturists did not consider that they were needed. The average rainfall in the south-east of the area was 400 millimetres ($15\frac{3}{4}$ inches) per annum and that diminished to 150 millimetres (about 6 inches) at Khartoum.

The rain-grown millet was planted as soon as sufficient rain fell, usually in July, and was watered by that falling subsequently. Rain occurred in June, July, August, and September, the heaviest falls being in July and August. On the 300,000-acre area, the average crop of rain-grown millet was 20,000 tons. Under irrigation there would be the following rotation: first year cotton, second year fallow, third year 40 per cent. millet and 60 per cent. lubia (a leguminous crop). It was expected that the 300,000 acres would produce 30 million lbs. of cotton lint, in addition to the seed, 15,000 tons of millet, and the lubia, which was used as cattle-fodder. The millet and lubia would be taken entirely by the native cultivators. Sowing and resowing of the cotton took place from the 15th July to the 15th September. Water was given every 12 to 18 days, the interval depending on the time of year, the waterings being rather more frequent in October, with wider intervals in the colder months of December and January. It was supplied on or shortly after the 15th July at the rate of about 450 cubic metres per acre. About fourteen waterings were given in all. The millet cultivation depended mainly on the rains, but sufficient water was allowed to ensure the ripening of the crop. This was given either at the time of sowing, at the beginning of August, or later, at the end of September or beginning of October, according to the circumstances of each year and the actual rainfall

The Author. on any particular plot. Lubia received about four waterings at intervals of 20 days, beginning in September.

With regard to the mortar in the dam, the production of the clay and, in particular, of the lime for the "homra" mortar in the 54,860 cubic metres of masonry, had been a matter of great difficulty. It would have been impracticable in the time to produce the required quantities for the masonry built in 1924, which was three times as much. It also had the disadvantage that it was very slow setting—an important point in a work which was being built rapidly. When the war made it necessary to consider the replacement of imported cement by a mortar made from local materials, it was decided to use the lime and clay in the most scientific manner by erecting a cement-factory to turn them into cement, rather than to employ the same materials in the form of lime and "homra." Even if the production of the necessary quantities of the latter had been practicable, it was estimated that there would not have been any saving in cost.

Regular discharge-measurements by current-meter had been and were being taken of the Blue Nile at a short distance below the dam and a few miles above the junction with the White Nile at Khartoum.

It would be interesting to see if the low-period discharge of the river was increased by seepage from the bed of the reservoir and also from the irrigated area, as envisaged by Mr. Strange. Owing to the general impermeability of the soil, the Author would be surprised if there were any appreciable increase.

In conclusion he wished to thank the members for the kind way in which his Paper had been received and to endorse all that had been said as to the efficient way in which the Contractors had overcome the many difficulties and successfully completed the works within the contract time, which was very short for the amount of work involved. To indicate the rate at which it had been executed, he might mention that one monthly certificate amounted to £E.220,000.