Discussion.

The PRESIDENT, in moving the vote of thanks, observed that irrigation was one of the oldest branches of engineering, and there was a large amount of information in the library of The Institution on the subject of irrigation the world over. But the subject seemed to become year by year more and more important, and Papers such as had been presented that evening could not but prove to be of the greatest possible value. The President.

Sir THOMAS WARD remarked that he felt very diffident in opening a discussion on irrigation-works in the Sudan, a country of which he had had no personal experience. The difficulties that had been overcome were clearly evident from the Papers, which were written in an extremely modest way and would undoubtedly be very valuable. He could only look at them from the point of view of experience gained in the Punjab, where the conditions were very different. Could Mr. Johnstone give some information with regard to the laying out of the plots? In the Sind Sagar Doab in the Punjab, an area of about 8,000 square miles, the plots had been laid out by Colonel H. L. Crosthwait, C.I.E., R.E., who had first made a study of the system used in the Sudan and had asked him whether he would prefer that system to the system of the Survey of India Department already used in the Rechna Doab, laid out into plots in 1906. Naturally he had preferred the latter system, though he knew very little of such an extremely technical subject as the laying out of large areas in perfectly accurate plots. It was difficult for those who did not deal with irrigators in the very intimate way in which engineers in Northern India did to realize what expense and anxiety resulted if the farms were not accurately laid out. In the Punjab Colony canals the Revenue Department had first laid out the plots, and then the irrigation-engineers; but both attained results of only limited accuracy, and eventually, after some experience, they had been very glad, about 1906, to accept the offer of the Survey of India to do the work. Laying out plots on the ground was not really surveying: a surveyor only mapped what he saw, and did not provide material for others to map. Colonel Crosthwait had, in fact, explained that he was providing a full-scale map. Any engineer faced with the problem of laying out such canals in desert places would be only too glad of information as to how to do it more correctly. The three-plot system adopted on the Gezira was Sir Thomas Ward.

Sir Thomas Ward.

intended, he believed, primarily for the rotation of crops, but he thought there was also some intention of reducing the risks of waterlogging. The tract did not seem to be likely to become waterlogged, because it had a good slope with an adequate fall to a deep river—very different conditions from those in the Punjab, where the falls were slight and the rivers were not deep, and where there was likely always to be difficulty, in some places at any rate, in getting the water away from the subsoil, or rather in preventing it from accumulating there. He would appreciate a little more information on the technicalities which had led to the three-plot system from both the agricultural point of view and the point of view of the question of waterlogging. It was easy to design and build a canal in these days, because so much experience had been gained all over the world; but on the question of waterlogging very little information was available, and anyone who added to that information would be doing a great service to humanity. It was distressing to find in an irrigated tract a valuable property, giving a very high yield, become a swamp by the rise of subsoil water. That was happening in some South American vineyards, and also in some villages in the Punjab. On the question of the irrigation of cotton, he gathered from Mr. Johnstone's Paper that the storing of water by night in the canals was due to the technique of watering cotton. He believed that agricultural engineers had gone into that very thoroughly and had a well-tried system of getting the best results out of the water. Any information that Mr. Johnstone could give on the subject would be valuable. Two very large canal-systems were now being built, one in the Punjab and the other in Sind; and the climatic and water conditions and the ample populations all pointed to the fact that, if cotton maintained its price relative to other crops, the lower part of the Punjab commanded by the Sutlej Valley project and the part of Sind irrigated from the Sukkur barrage would become a cotton-growing country that would vie with Egypt. Irrigation-engineers in those two provinces would realize how very important agricultural research was as affecting the control of the water. The storage method employed in the Gezira canals could not possibly be used in the Punjab; if the soil was taken from inside the channel to strengthen the banks, in one season the redundant section was expected to silt up. During the process the channel required much attention. If the redundant area was fairly narrow, the silt deposited itself on the bed and there was a risk that breaches would occur; if it was broad, the stream meandered, and again the silt had to be cut through. Engineers in Northern India had had a good deal of

Sir Thomas Ward.

experience of escapes and would envy the Gezira canal its ready access to the river on its right bank. In Northern India escapes were only of service at the opening of the canal, when they helped to reduce the supply and at times to prevent breaches. Unfortunately, silt soon reduced the size of the channel to that needed to carry the small volumes escaped, and it became useless; therefore the water-courses to the fields had to be used as escapes, which sometimes resulted in damage to the crop. The cultivator had perhaps watered his fields heavily before an oncoming monsoon, owing to drought conditions prevailing, due to the monsoon being delayed. When the rain came it provided water which would have been more than sufficient for his crop even if it had not been irrigated. If the canal was not closed fast enough the field got another watering from escapage which might be more than sufficient even if arid conditions still prevailed. In an endeavour to avoid that risk, telegraphs were provided; the work of regulating the canals during the monsoons was carried on in intimate touch with the meteorological authorities, who sent warnings; and the canal staff were supplied with the daily synoptic weather charts of the whole of India. But there were times when heavy storms outstripped the news and damage was done to crops, and the irrigator was naturally anxious lest the canal officer might not be alert enough to save him from such flooding. With regard to weirs, it was stated on p. 87 that "The heads of major distributaries are grouped at or near the control-regulators on the main canal. In each group the width of each head regulator is proportional to the area served, and the sills of the weirs are all at the same level." He had found that system being used by the Baluchis in the Helmund valley, near Kuh-i-Khan Nahsin. Tamarisk-mat revetments were used instead of masonry, and a tamarisk pole was trimmed into a beam about 4 inches deep and 2 inches wide, which was ingeniously arranged so that if a man wanted to swindle he would have to push down the end of the beam in his canal and thereby raise the other end in another canal, and that would make such a difference to that canal that it would be at once noticed. He had not been able to discover where the Baluchis had got that idea from. He had found nothing so elaborate in Seistan itself, where the irrigation systems went back to the dawn of civilization. There were only one or two masonry works—one very ancient bridge with here and there signs of outlets. When Nadir Shah passed through Seistan on his way to Delhi in the eighteenth century he devastated the Helmund valley, and it had remained derelict until it was used by the Baluchi tribes. They said they had dug the canals about 60 years before he (Sir Thomas Ward)

Sir Thomas Ward. passed through, so it was possible that the system had been devised at that time. He did not think it had been done by a European, because he was informed at the time when he went through that only two Europeans had gone through before, one being a Frenchman, who had not mentioned the matter, although he had claimed that he found traces of a celebrated dam at Rudbar.[1] Sir Thomas Ward had also searched for remains there, but he had not found any signs of masonry works. Now that Afghanistan was adopting Western ideas, there was a chance that irrigation-works might be built in that valley. The possibilities were magnificent, and the system he had described might be found of use to distribute the supply equitably. The silt in the Gezira canal seemed to resemble in quality that carried by the water flowing in the channels towards the tails of the large canals in the Punjab. For example, the bed of the last 12 miles of the branch of the Western Jumna canal, as it entered Delhi about 150 miles from the head works at Tajawala, was graded level to obtain command to irrigate the famous Delhi gardens; the water-surface slope was, however, about 1 in 50,000. The absence of silt spoil on the banks showed that silt had never given trouble. Nevertheless, the waters were muddy enough to keep down the growth of weeds. Towards the tails of long channels the silt consisted mainly of very fine clay which, by adhering to the sides where the velocity was checked by the grass, built up the narrow deep section so characteristic of channels in the deltas of rivers. Internal borrow-pits were not suitable for purposes of strengthening banks far down long channels: silt was trapped slowly, and during the process weeds were fostered. Mr. Johnstone would add to the value of his Paper by stating whether trouble had been experienced from weeds, and, if so, in what reaches. When the Kennedy[2] equation was known, it gave a ready means of comparing the quality of the silt carried by channels.

Mr. Saner. Mr. J. A. Saner remarked that the pressure on some of the sluices described by Mr. Russell amounted to 200 tons, and it would be interesting to learn whether Mr. Russell had made any calculations as to the power required to raise the doors. Some of the sluices were not on live-ring rollers, and therefore it might be possible at the same place to compare sluices that were not provided with a live ring with those that were. He had not heard that a caterpillar live ring had been used before for sluices. A difficulty with live rollers

[1] Maj.-Gen. Sir H. C. Rawlinson, K.C.B, "Notes on Seistan," Journal Royal Geographical Soc., vol. xliii (1873), p. 278, and J. P. Ferrier, "Caravan Journeys," p. 410. London, 1856.

[2] Minutes of Proceedings Inst. C.E., vol. cxix (1895), p. 281.

Mr. Saner.

was that they were left behind when the door was raised, and putting the door on a caterpillar seemed to him a very happy way to get over it. On the Weaver Navigation there were merely four rollers, one on each corner of the door, and they were very effective. To his knowledge they had been in use for a great many years; some of them were put in about 1872, and those which had been taken out or examined were still in good working order and required no alteration. He had the opportunity a short time ago of attaching an electric motor to one of the sluices, and he found that a sluice which weighed $3\frac{1}{2}$ tons and had $37\frac{1}{2}$ tons pressure against it could be raised through 1 foot by the motor at an expenditure of 0·324 electric unit. That showed that if electric power could be applied to sluices in the ordinary way on a navigation like the Weaver, it would be possible to save a very large amount of labour, because four men had been required to raise the sluice he had referred to at the same speed as the motor raised it. He had been very much interested in the way the sides of the sluices on the Gezira had been stanched. That was done on the Weaver by timber whose specific gravity was very nearly the same as that of water. The timber was forced into the corner by the pressure of the water. In 1886 he designed a sluice divided into two paddles, the bottom half picking up the top half: it had been working quite well on that principle, which had been adopted in order to save altering the gearing, so that only the same power was required to work against double the pressure.

Mr. Buckley.

Mr. A. B. Buckley observed that the project should be of very great value to the Sudan. He did not think Mr. Johnstone had done full justice to the difficulties encountered in carrying out the scheme. There was very little building-material and little water; during the rains the ground became impassable and very difficult to survey, and the heat was usually intense all the year round. The main canal had what he thought were the best proportions—a very important matter, affecting its silt-carrying properties. Its proportions corresponded very closely to those advocated in recent years in Egyptian practice, and it might be of interest to mention how those proportions had been arrived at. If a canal was too deep in proportion to its width, it silted rapidly. Certain canals in Egypt never silted. Sections of those canals had been taken, certain proportions for different discharges had been worked out and tabulated, and a formula had thus been evolved. It was purely an empirical way of arriving at a type, but it had answered very well. The escaping-power provided for the canal seemed excellent; 70 per cent. of the maximum possible discharge of the canal could escape to the river. He desired to congratulate Mr. Johnstone and

Mr. Buckley. the contractors on the excellent work they had done and on the way in which they had overcome all the difficulties. As to the operation of the scheme, however, he was not quite so happy. Mr. Johnstone mentioned certain disadvantages of the method devised for water-distribution. There were disadvantages from the points of view of silt, agriculture, and hygiene, as well as of the equitable distribution of the water, and lastly of capital cost. Mr. Johnstone was not responsible for those disadvantages, and Mr. Buckley proposed to elaborate them. It was now known fairly well what quantity of silt was carried by the Nile. The silt-content varied widely from month to month. It was shown in Appendix E (p. 92) that, in the season 1926–27, 913 million cubic metres of water flowed down the canal for irrigation. Many determinations of the silt load of the Nile in Egypt had been made during recent years, and would be found, for purposes of comparison, in the Institution library; for the present purpose a determination of the Blue Nile water itself made by the Wellcome Research Laboratories at Khartoum was the best to take, and it showed that the average content of silt in the water during July was 1,000 grams (about 2·2 lbs.) per cubic metre. In August there was 2,000 grams; in September 800; in October 280; in November 110; in December 20; and so on until April, when there was merely 8 grams per cubic metre of water. On that basis the total quantity of silt carried by the canal during the season from July to April was 380,000 tons, which was equal to about 250,000 cubic metres. It was stated in Mr. Johnstone's Paper that irrigation by night was not possible, that in view of the small allowance of water allotted to the Sudan it was imperative to store water by night rather than escape it to the Nile, and that in order to avoid silting up the main canals, a system had been devised for night storage in the minor distributaries. Those had been divided into four sections by means of weirs. The distribution had therefore been so arranged that in the evening the water in the top reaches of the distributaries began to pond up until it rose to 30 centimetres above the level of the first weirs; in the meantime it overflowed until the next reach filled; and so on for the last two reaches. Obviously, the top reaches would silt up very soon. The volume of earthwork in the distributaries was given as 5,758,000 cubic metres, and, allowing for excavation in foundations and escapes, apparently there was about 5½ million cubic metres in the distributaries, apart from the main canal. It would be reasonable to assume that in the minor distributaries about 3 million cubic metres had been excavated. The quantity of silt carried would therefore be enough to silt up all the distributaries in about 12 years. That, of course, would not happen. What he thought would happen was that the minor distributaries would silt in the first reaches, and the silt would have to be cleared. Mr. Johnstone stated that the system worked well, and naturally in the first two seasons the silting might not be apparent to an objectionable degree. When new, the whole system was full of borrow-pits which would absorb a great deal of silt, while the main canals themselves would also receive a certain quantity in adjusting themselves to their working-sections. What evidence of silt-deposits was there now in the minor distributaries after the third working-season? From the agricultural point of view to deprive the land of silt was a disadvantage. The percentage composition of Nile silt was: silica 48; oxide of iron $12\frac{1}{2}$; alumina $19\frac{1}{2}$; lime $3\frac{1}{2}$; magnesia $2\frac{1}{2}$; potash 2; soda 3; phosphoric and sulphuric anhydride $\frac{1}{4}$; carbon dioxide $\frac{1}{4}$; combined water 7; and organic matter $1\frac{1}{2}$. From that it appeared that the fertilizing power of Nile silt, in the sense in which the expression was ordinarily used, was negligible. The silt, however, was useful, for a certain reason. The texture of the soil, quite as much as any nourishment which it might contain or might have added to it, caused a plant to flourish. With a very compact soil the surface water could not reach the roots by gravity, neither could water reach them from below by capillarity; and therefore the use of the silt was not so much to fertilize, but in the first instance to create a suitable soil, as the Nile had done in Egypt, and subsequently to permit of its retaining this essential characteristic under intensive cultivation. The soil in the Sudan was heavy, as evidenced by the way it cracked under the influence of the sun's heat, and it had been found that one-third of the cultivable area had to remain fallow every year. The soil very badly needed to be lightened by an admixture of silt, and therefore the system of water-distribution actually adopted appeared to be unfortunate. Mr. Johnstone gave the yield of cotton as 488 lbs. per feddan in the first year and 492 lbs. in the second year. The Chairman of the Sudan Plantations Syndicate, in his report to the annual general meeting recently, had stated that the yield of cotton for the third season had fallen to 328 lbs. per feddan. No doubt a probable cause of that fall in yield would be traced to the heavy land, although it was also due to unfavourable climatic conditions. From the hygienic point of view also, the system was open to criticism, because it held the water above ground-level for prolonged periods and produced infiltration, with corresponding opportunities for the breeding of mosquitos. Malaria had been prevalent there even before irrigation was started. Therefore everything should be done to keep the water-level in the irrigation Mr. Buckley.

Mr. Buckley. system as low as possible. Again, the system was unsatisfactory from the point of view of water-distribution. That could be achieved in an ordinary canal-system by means of properly graded channels with outlets to field channels also properly graded to a definite slope. Canal-systems were usually so designed, but even then they were subject to a big disadvantage. A canal had necessarily to be designed for the maximum discharge it had to carry. In Egypt, as an example, that maximum discharge lasted for perhaps 3 weeks in the year, and at other times the discharge was much less and might fall to as low as half the maximum. Under those conditions regulators along the canals were operated and the water was ponded up, with the result that the cultivators upstream obtained less water than did those immediately above the regulators. The system adopted in the Gezira established a chain of tanks, thereby exaggerating that defect. Therefore the system seemed to him to be really the negation of equitable water-distribution, because, according to the figures given in Appendix F (p. 93), the cultivators at the lower end of a reach, on opening their culverts in the morning, would get twice as much water as those at the top end. The ponds would then empty, and the consumers downstream would continue to get more water, while those upstream would not get even the discharge which they might have received under the worst conditions which could have obtained had the canals been designed to smaller sections and properly graded. The question was whether there was any better solution. Mr. Johnstone explained why it had been considered that water could not be escaped to the Nile. That was, no doubt, valid at certain times of the year after about November. During the flood, however, the only time when the Nile carried a heavy load of silt, there was ample water for all. Of the 380,000 tons of silt carried by the canal in the whole working-season, 31,000 tons was carried at the end of July, 184,000 tons in August, and 106,000 tons in September, making a total of 321,000 out of 380,000. The bulk was therefore carried during the months when the discharge of the Nile was ample for all requirements, and he could see no objection to escaping the silt-laden water to the river during the night, instead of storing it in the minor distributaries. When, under these circumstances, the distributaries would be opened in the morning, the silt-laden water would flow through them at a good velocity and the silt would be carried to the land, to its benefit instead of to the detriment of the minor distributaries. Under existing conditions the minor distributaries would certainly deposit for 8 hours out of the 24 in the day; of the remaining 16 hours a large part would be spent in lowering the levels of the ponds; the water in them would be practically stagnant and silting would occur. Therefore, there was no chance of carrying any silt on to the land. If the water was escaped, as he suggested, during July, August, and September, water could be stored in the main canals without any danger of silting them up. Storage in the minor distributaries would then be no longer necessary. It seemed, therefore, that the adoption of that particular system of water-distribution had resulted in wholly unnecessary extra work in the minor distributaries, which he estimated approximately at 2 million cubic metres of earthwork, with a corresponding increase in capital cost. From the point of view of working-costs, he estimated that a reasonable grant for maintaining the canal-system for 300,000 feddans might be about £20,000 per annum, while the annual clearance of silt might entail an expenditure of £25,000 and therefore double the cost of maintenance; and, as the bulk of the silt would be deposited at the beginning of the working-season, while the month of maximum demand, as shown by Appendix E, was October, there was great danger that after a few years the system would be strangled by deposits of silt in the head reaches of the minor distributaries and that it would be unable to deliver the requisite volume of water in the month of maximum demand. Mr. Buckley.

Mr. E. S. LINDLEY remarked that the bell-mouths at the front of the sluice-tunnels were apparently similar to those on the Assuan dam. That was an imperfect form of bell-mouth, in that it would not allow the tunnel to flow full. He imagined the reason for adopting it was that it had been calibrated; but it would be simple to calibrate a more perfect bell-mouth, and it would save waste in piercing the dam with a tunnel-opening which was not filled with flowing water. He was strongly inclined to support Mr. Buckley's objections to closing irrigation at night, and he would be very interested to learn why night irrigation was pronounced impossible. Apart from the silt difficulty to which Mr. Buckley had referred, another point that was probably as serious was the greatly increased absorption loss through the extra waterway provided in the channels and the wetting of the banks every night and the drying of the surface in the sun by day. The standing-wave weir used for measurement where less than a clear over-fall was available was stated to be independent of drowning up to 75 per cent.; and in his original Paper Mr. Butcher took no less than 2½ per cent. reduction of discharge as the standard of independence for practical purposes. That standard could be achieved by a weir without any glacis, and was very considerably exceeded by weirs and flumes used in the Punjab. Sir Thomas Ward's remarks might have given the impression that in the Punjab, when rain fell, canal-supplies could not be Mr. Lindley.

Mr. Lindley. stopped and escaped quickly enough to avoid flooding the fields. That was not in accordance with his own experience: in 23 years he had not known many men to admit having had enough water; and as to complaining of getting too much, that was almost unthinkable.

Mr. Stokes. Mr. A. S. STOKES observed that Mr. Saner had alluded to the fact that some of the gates were of the free-roller type commonly known as the Stoney sluice, and some of them were of the sliding kind. He thought the reason for that was fairly clear. All the roller gates were at a deep level in the dam itself, under a high head, and therefore it was necessary for them to be capable of being moved with a minimum of friction. The gates of the sliding type, known as the Butcher gates, were on the subsidiary canals and were not deeply submerged; and, as the head was low, the effort required to move them, although considerable, was nothing compared with the effort that would be required to move gates of the same type submerged as deeply as were those on the dam. The sliding type of gate used on the canals was not a particularly good form of gate from the point of view of efficiency. The gate had been put in in the full knowledge that it was about the most inefficient gate that could possibly be put in, and that very considerable gear-reduction was necessary to move such a gate. The intention had been that the gates should not be capable of being interfered with readily, and in fact inefficiency was a virtue in that case. The type of gate used at kilometres 57, 77, and 99, with rollers on an endless chain, was not at all usual, but it had been used in several cases fairly satisfactorily. There were, however, several objections to chains of that kind, chiefly the large number of small moving parts which were liable to jam. The great advantage of the wheel type of gate described by Mr. Saner was that when it was hoisted out of the water it did not leave behind a nest of rollers in the water which rattled in the current, causing wear. Another obvious advantage of the wheel type was that it was usually cheaper to make, but the disadvantage was that the wheels were very much more likely to stick on their axles than were the rollers in the Stoney type of gate. That could be overcome only by having wheels of very large diameter on relatively small axles. In many of the older installations only a small groove was provided for the accommodation of the gates, and the wheels were often too small in diameter to be satisfactory. He thought that in most of the large installations now being put in, such as the barrages on the Indus and on the Nile, the large-roller type of gate as opposed to the Stoney type was being used. Quite a number of installations to-day were electrically operated.

Mr. Johnstone. Mr. JOHNSTONE, in reply, remarked that in 1906 the Sudan Government decided on a policy of demarcation and registration of ownership of certain areas in the Gezira Plain. As a preliminary step to that settlement the Survey Department of the Sudan Government demarcated the whole of the area under consideration into sections, 1 minute of longitude broad, and 1 minute of latitude in length. At the corner of each section a permanent beacon was placed, consisting of a pipe driven into the ground, into which a rod was let, with cross plates at the top showing in English and Arabic figures the longitude and latitude. The Survey Department of the Egyptian Government ran a series of levels across the area to be canalized, using the beacon marks as a base (generally on an east and west line) and running three lines east and west in each minute interval, which they completed in 1919. On the result of that levelling the Survey Department issued contour maps with contours at ½-metre intervals, on which a part of the system was laid out. It was found, however, that the contours did not give sufficient information, so at a later date, at the request of the Irrigation Department, the actual levels observed were shown on the maps, as well as the contours, which gave a great deal more information. On the basis of those maps the alignments of the remaining canals and drains (described on p. 74) were laid down; they were referred on the plans to the minute beacons by off-sets, and then set out in the field from the beacons. When actual levelling was in progress along the alignments of those canals, levels were taken 200 metres on each side of the alignment to check its correctness; in practice it was found that the contour levelling was so good and the ground so uniform that the alignment laid out on the maps did not often have to be changed. Wherever possible the setting-out of the alignment of canals was checked against other canals, as in the case of a series of parallel canals where the interval between one canal and another was easily dealt with. The lay-out of field channels was designed in the same way on the contour maps in conjunction with the distributaries and drain lines, to ensure sufficient and suitable fall. Means of warning the irrigation staff of impending rainfall, mentioned by Sir Thomas Ward, were not available in the Sudan, nor, he imagined, were conditions in the Gezira similar to those in India. Rainfall was usually very local, of short duration (rarely as much as 24 hours), and at varying intervals of time, but was sufficiently heavy to drown young crops if irrigation-water could not be quickly turned off. It was at such periods that the beneficial effects of the escapes were apparent. Since the scheme was started no very heavy rains had fallen, and it had not been necessary to close down the whole system suddenly, so the escapes had not been used heavily. The question of the waterlogging of the soil, mentioned by Sir Thomas Ward and Mr. Buckley, had received much consideration. **Mr. Johnstone.**

Mr Johnstone. The conditions in that part of the Gezira which had been canalized were different from those in most irrigation schemes. The actual subsoil water was generally 80 feet below the ground-level, but it was overlain by the extremely dense clay, into which water penetrated with difficulty—usually not more than 4 feet under irrigation conditions. It was, however, very apparent that soil was more fertile on the tops of ridges, and definitely less fertile in depressions where rain-water collected and lay. The three-period rotation —cotton, leguminous, and fallow—had primarily been adopted solely for crop-rotation, though at one time a four-period rotation had been under consideration, with a view to dissipation of the salt in the soil, of which there was a certain amount, increased each year by the salt in solution in the Nile water; however, the existing rotation was considered sufficient. On the experimental area of Taiba, and later on the Gezira Research Farm, continuous cultivation of cotton, and cotton planted every other year, preceded by fallow periods and various crops, leguminous and otherwise, had been tested, but up to the present the three-period rotation had been found to be the most satisfactory. The present system, whereby irrigation ceased on the 10th April, subjected one-third of the whole irrigated area to at least 3 months of baking and cracking under a tropical sun, and one third to a period of 6 to 8 months of similar treatment, and the remaining third to 15 months of fallow condition, which in practice dried the soil very effectively and amply provided against waterlogging. The conditions under which the main canal drew water from the river were such as to minimize the quantity of silt drawn into the main canal. In order to command the main canal the water-level in the river had to be raised to 417·20 upstream of the dam, and the water was thus checked before reaching the main-canal intake. The actual intake-channel took water at right angles to the direction of the current in the river. Both these conditions tended to reduce the entrance of heavy silt into the main canal. Silt samples taken downstream of the head-regulator gave the following mean results :—

	Solids in Suspension : Parts per Million.			
	1925	1926	1927	1928
August	921	928	no return	273 (end July)
September	244	213	233	200
October	36	70	38	76
November	36	28	23	43
December	15	40	20	20

Mr. Johnstone.

The silt-content in water in the lower reaches was somewhat higher, and that was no doubt due to fretting of the banks by wave-action. So far no difficulty had been experienced from excessive deposition of silt; in fact difficulty had been experienced in the minor distributaries in finding sufficient silt for the maintenance of banks. So far as weeds were concerned, the main canal and the major distributaries had given no trouble. A certain number of weeds did occur in the minor canals. These were well in hand and were not a source of anxiety. So far difficulty from weeds had arisen on sanitary grounds, as the kinds of weeds which grew encouraged the breeding of mosquitos and Bilharzia snails. In the tail reach of one minor distributary only had a floating weed growing from the bed of the canal appeared. The weed that gave most trouble was known locally as sed grass, which occurred on the berm of the canal in shallow water. It grew in clumps from bulbs about 2 feet below ground, and had to be dug out. The normal and most satisfactory method of irrigation was undoubtedly a continuously running system; but there were certain difficulties in the Gezira Irrigation Scheme that made intermittent irrigation necessary. The cultivators were generally a pastoral people unused to agriculture under other than rain conditions, and they required close supervision to obtain the best results. That supervision was impossible at night. Moreover they were distinctly unwilling to go into the water at night, for fear of snakes and scorpions. The soil was exceedingly friable, and if the containing banks in the fields were unattended during flooding they would break, and damage to the crops might result. The Government were very anxious to attract the resident population, who were also the landowners, to take up the cultivation of their own land willingly, and that they should carry out their work satisfactorily with a reasonable amount of inspection only and without undue compulsion. It was also in the interests of all parties concerned that the best results should be obtained immediately, and that the scheme, agriculturally and financially, should be a success; and that had undoubtedly been achieved. Alternative methods to that of storing water in the minor distributaries had been considered, but had been found impracticable. Escapage of water by night through the escapes would have necessitated a larger section in the main canal to carry the water necessary to irrigate the area in 12 hours instead of 24 hours, with a consequent increase in the cost of construction. Regulation in the major distributaries would have become very complicated, in view of the fact that the water-travel to the first irrigating-point in extreme cases ranged from zero at the head to 36 kilometres at the tail of the system. The great advantage of the present system

Mr. Johnstone. was that it was possible to maintain a perfectly steady discharge throughout the whole system except downstream of the head of the minor distributary, where the operation became entirely automatic; and that steady discharge reduced the possibility of silting-up the larger channels. The actual process of silting in the minor distributaries had so far proved more of an advantage than a difficulty in the maintenance of banks. The only disadvantage so far experienced had been the seepage of water through the canal-banks, which was very local in its effects, and was a sanitary rather than an agricultural question. The absorption, mentioned by Mr. Lindley, had not yet been measured, and was difficult to measure; but it was probably not great, judging from the actual seepage of water through canal-banks.

The Paper, being purely on the engineering side of the Gezira scheme, only touched on the operations of the Sudan Plantations Syndicate. The Syndicate had been very largely responsible for the success of the scheme by their very practical methods and their efficient organization. It was a very big achievement to start a scheme of cultivation under irrigation conditions of such magnitude, with cultivators entirely ignorant of that type of cultivation, and a staff of British inspectors with only limited experience on small areas served by pumps. The Syndicate took over the Taiba experimental farm in 1911, and worked out methods of cultivation and collected valuable data on which the whole scheme was based and the lay-out of canals designed. In 1914 they laid out and canalized the Barakat experimental farm. In 1921 they constructed the Hag Abdalla pumps, and brought 7,000 feddans of cotton under cultivation in the area to be subsequently incorporated in the scheme and irrigated from the dam. In 1923 they installed the Wad El Nau pumps and cultivated a further 10,000 feddans of cotton. The starting of these areas throughout the Gezira was a material factor in giving confidence to the people in the advantages of cotton-growing under irrigation conditions, and assisted in starting the general scheme. During the construction period the Syndicate, in collaboration with the Government, settled all the tenants on their plots, constructed their water-channels for them, amounting to 4980 kilometres, ploughed their land, and constructed houses, offices and store-sheds throughout the developed area, for their field inspectors. The Syndicate were entirely responsible for the management of the scheme and the disposal of the cotton. The inspectors in the field were responsible for assessing the volume of water required and for its control and distribution once it had passed into the distributary canal. They organized and ran a fleet of ploughs and ploughed for the tenants the whole area to be put under cotton. Twice each year they supplied to the tenants the seed for sowing.

The inspectors directed each cultivator in the watering, cleaning, and picking of the cotton-crop, and made him maintain sanitary conditions in his water-channels where mosquitos might breed, and clear out his water-channels each year. They advanced money to the cultivators during the period of the growth of the cotton. They operated a light railway for the transport of the cotton to the ginning-factories, and ginned, exported, and marketed the cotton, paid the cultivator on the proceeds of each individual out-turn, and generally cared for the cultivator. Mr. Johnstone.

Correspondence.

Mr. G. W. GRABHAM observed that Mr. Johnstone had referred to the geological formation of the Gezira plain. Igneous and metamorphic rocks, including bands of crystalline limestone, underlay the soil and subsoil on the west and south-west sides of the plain, and formed the base on which rested the Nubian Sandstone (Cretaceous). After the deposition of the Nubian Sandstone, the region had been subject to denudation for a long period, and a great deal of the sand stone had been removed, so that now the principal mass remaining within the Gezira was that forming the low ridge included within the 415-metre contour. The Nubian Sandstone also existed beneath the northern and eastern part of the area, but it was covered by later deposits. After the period of denudation there had arisen a system of streams draining, like the present ones, from the south east. They had flowed in a valley on the eastern side of the sandstone ridge and debouched northwards and westwards from it, forming a delta extending across to where the White Nile now lay and northwards as far as Khartoum. After the formation of that inland delta, a blanket of loess, or wind-deposited soil, had been laid down over the alluvial deposits. The material of that loess was not the sand that was rolled along on the surface and caught by the bushes, and formed dunes on the desert's edge. It was composed of the fine dust that was raised into the air and carried far afield, gradually settling among the vegetation in the more favoured regions some distance south of the desert. It contained relatively little quartz, and a good deal of lime and alumina, and it formed a very heavy and impermeable clay soil. Owing to the manner of its deposition and its even thickness, the surface of the loess exhibited the topography of the deltaic alluvial deposits on which it rested. The Blue Nile, as it was known to-day, was a relatively modern stream which had cut its well-defined valley into the loess and older alluvial deposits. Along the banks were narrow strips of alluvial Mr. Grabham.