Colonel GREATHED stated that the bed of the river Jumna where the weir was constructed at Okhla consisted of nothing but fine sand. There was a considerable stream of water passing down during the rainy season. A different form of weir had been considered more suitable for the head of the Lower Ganges Canal at Rājghāt, where no stone was available. Continuous experience had shown that the best safeguard for a weir was to reduce, as far as possible, the velocity of water passing over it by extending its length, as thereby the dangerous action of the water upon the soft sand of the river bed was mitigated. But scour, and depression of the surface and bed of a river with such a bottom, must occur. It was necessary to defend the main body of a weir by a long talus. The sandy beds of these rivers were always raised on the up-stream side, consequently that portion of the work would be safe from scour. The main defence was presented by a line of contiguous deep wells on the down-stream side of the weir, which were protected by a talus of crib-work of rough boulder stones. The foundation of the Okhla weir across the Jumna was on the level of the top surface of the sand, or actual bed. The slope on the up-stream side of the weir was 4 to 1. The longitudinal walls were of rubble masonry.

Mr. J. F. BATEMAN said everybody present would recognise in the works carried out by the Indian Government the great benefit that had been conferred upon the country at large. The Paper was very interesting, but it was almost impossible to have it discussed by the Institution. There were no engineering details beyond a general description of canals of vast magnitude which irrigated a certain extent of country, and the only subject which could come under the ordinary process of discussion was the construction of the weir at Okhla. He confessed he had not obtained that accurate conception of the mode in which the weir was constructed to enable him to offer any critical observations upon it. He understood that on the up-stream side it had a slope of 1 in 4, and that there were continuous cross walls, with a broad base formed of dry rubble, and then a long slope of dry rubble on the down-stream side. It appeared that there was a head of water of 5 ft. flowing over the crest of the weir at a velocity of 9 ft. per second or 10 ft. per second at one part, and which increased to 18 ft. per second lower down. Such information as this was useful and valuable as a record of practical construction and working. The weir proposed to be erected at Rājghāt appeared to be a cylinder construction of wells sunk into the sand, filled apparently with concrete or other material; but in this case also the Paper had not conveyed to his

mind any impression as to the mode of construction. There could be no question as to the importance of irrigation works, and the great benefit they were likely to confer upon the country; and the Institution could not but feel indebted to the gallant officer for having taken the trouble to put such a series of details on record; but, practically, the Paper was one which did not admit of much discussion.

Mr. VIGNOLES said that the Paper contained a mass of valuable topographical information, but there was not a sufficient amount of engineering details to discuss the most interesting point which had been raised, namely, the best form of construction for a weir where there was a large body of water tumbling over it at a great velocity.

Colonel GREATHED said he feared he had not sufficient materials at hand to enable him speedily to afford more precise details. The great extent of the district over which the works were spread rendered it impracticable to review within the limits of one Paper the general scope of the scheme, and, at the same time, to furnish the details of works of construction. It had appeared to him that the proper course, in the first instance, was to describe the principles on which the scheme was founded, and thus to establish a base for further discussion on specific works and details. The weir proposed to be erected at Rājghāt, at the head of the Lower Ganges Canal, consisted of a vertical wall of brick or rubble masonry, faced with ashlar, constructed to raise the level of water in the river 6 ft. 6 in., and thereby to insure a constant supply to the canal heads which are placed just above it. The river fell over the wall upon a countersunk ashlar platform; a row of continuous wells of moderate depth would be constructed under the vertical wall, and a similar row of deep wells along the tail of the platform. A slope of crib boxes filled with heavy material was proposed for the down-stream protection, and a dry stone slope for the up-stream side of the wall. The flooring of the weir would be of ashlar. At a future time he proposed to present to the Institution accurate drawings of the weirs as constructed, and of the effect upon the Okhla weir of the extraordinary floods of 1871. The down-stream cross wall was then completed to full height, but the up-stream wall was not commenced. At that time, to protect the cross wall, the slopes of dry stone had been carried to about 15 to 1 on the down-stream side, and to about 4 to 1 on the up-stream side. The effect of the flood was to silt up the bed to the level of the up-stream wall, and no damage was done to the boulder talus of 1 in 4; but from the

point at which the velocity increased to 18 ft. per second over the weir. The surface of the down-stream slope was scored by holes, or sometimes by cuts carried down to the tail of the weir, where there was a considerable hole. The safety of the weir, however, was at no time seriously threatened. The holes were not of great depth, and at the end of the season were repaired at small expense.

Mr. BARLOW inquired whether the flat slope of the weir was considered necessary as the result of previous experience in India, or was it made for the first time in the case of the Okhla weir?

Colonel GREATHED replied it was not the first time the slope was carried to that extent. The slopes of the weirs of the Kistnah and Godavery were made much steeper. The stone facings of those works were, if he could trust to recollection, cramped and laid in mortar, whereas, at Okhla, the face blocks were merely packed dry as quarried. The height of those works was also considerably less than that of the weir at Okhla. The annual cost of repairs of the Kistnah and Godavery weirs had at first been great, and consisted chiefly of additions to the tail of the weir. Some stones had been cut away, others had been thrown in, and in that way the slope was prolonged. In the Pennair river, when the weir was carried away for the first time, the down-stream slope section was increased to a slope of 1 in 10. After the second failure the slope was altered to 1 in 20, and at that point it stood. As the conditions of the Pennair river closely resembled those of the Jumna, the regimen which had succeeded in the first case was adopted for the other. There was a little falling in at the 'toe' of such weirs, where the slope was of small thickness. The great object was to keep the scour off the main body of the works.

Mr. PARKES asked what was the position of the weirs with regard to the courses of the rivers, and, severally, their lengths as compared with the general breadths at their sites?

Colonel GREATHED replied, the weirs had been placed at right angles to the rivers. The length of the Okhla weir was rather in excess of the width of the extreme flood level, and was so designed to reduce the velocity of the water going over, as much as possible. In the case of the proposed weir at Rājghāt, the length of the weir was less than the average width of the river bed, but was in excess of the width of the running water in highest floods, and was so designed that the maximum velocity of the water going over it should be under 8 ft. per second. The object of the weir was to raise the water 6½ ft., and to save that amount of digging for the first twenty miles. The Okhla weir, as constructed, raised the surface of the water 8 ft. 6 in. That would be the level

of the ordinary supply of the canal; the cill of which was fixed 11½ ft. above the original river bed in order to lessen the influx of silt. When the water in the river was above 8 ft. 6 in. it tumbled over the weir, and, practically, it kept at, or above, that level during the low-water season. In dry weather an increased supply would be obtained by raising the crest of the weir 1½ ft. by planks or movable shutters.

In answer to a question he stated that the Agra Canal weir at Okhla was in operation, and the lower Ganges Canal weir at Rājghāt had just been commenced. Much discussion had taken place as to whether it was desirable to give the greatest support to a weir on the up-stream side or on the down-stream side. Experience had shown that, under the circumstances which affected the Rājghāt weir, the strain was caused by the retrogression of the river bed on the down-stream side. But, under other circumstances of soil and slope, a different conclusion might be arrived at. In the case under discussion the river bed consisted of fine sand only. It was found that the bed and surface of water on the down-stream side of the weir had been lowered 3 ft. in consequence of its construction, and the retrogression which this alteration tended to cause required to be carefully checked. At Okhla, a supply of stone on the spot rendered the broad construction preferable. Where material was not abundant safety must be sought in deep foundations capable themselves of resisting retrogressive action.

Mr. BRUNLEES said it would be interesting to have a description of the construction of the portion of the weir at Okhla, over which there was a velocity of 18 ft. per second. He hoped that the Author would favour the Meeting with a sketch of it, as he was sure it would be a matter of interest to all.

Mr. REDMAN said it was to be regretted that the Paper had not been accompanied by general cross-sections of some of the leading arterial canals, showing their formation in cutting and embankment; and, undoubtedly, there was a paucity of that technical information which should have illustrated the subject. But it might reasonably be assumed that the Author only intended the present as the first of a series. When the magnitude of the works and the great number of engineers employed upon them was considered, it almost read like a fairy tale, to find that over so extensive a tract of country, canals, costing, as these had done, large sums of money, yielded so high a rate of interest as 6½ per cent., and at the same time conferred incalculable indirect benefits upon the country.

The weir which had been erected at Okhla was certainly a gigantic work. It was 2,000 ft. in length—double the length of London Bridge—constructed across a large river. The question at once suggested was, what were the functions of the two vertical walls in the centre of its section? He took it for granted that they performed two important duties, both during the course of construction and also when the dam was finished. In construction they held up the crest of the work, and formed the nucleus of the dam; and when finished, they undoubtedly prevented the spread of one of those breaches which occasionally occurred on the lower slope, as described by the Author; and, so far, they had proved conservative. He did not consider the precise formation of the 'toe' of the slope in a weir of that construction to be of much importance. Undoubtedly, the 'toe' of the slope, in an ordinary embankment for sea defences or reservoirs, with a slope of 4 to 1 or 5 to 1, did perform important functions, and, unless it was very carefully made, the wall was liable to fall, from inattention in that particular. Many engineers sheet-piled the 'toe' of the slope; others dug a trench and filled it in with a mass of concreted matter, forming a 'toe' on which the slope of the wall at a steep incline rested, and prevented the tendency of the wall to slip forward. Again, where exposed to recession of the tide, or in the case of a reservoir with a small amount of water—in either case the wall was liable to be undermined; but in this particular instance those functions were reduced to a minimum; and consequently the slope with an incline like that of 20 to 1 had, in point of fact, very little 'toe' at all.

With reference to the proposed weir at Rājghāt, it appeared that there was a special construction through the heart of the work formed by a series of cylinders. That row of cylinders would perform the same function as the two parallel walls which had been constructed across the river in the case of the Okhla weir. A question had been asked about the upper crest of the proposed weir at Rājghāt. He assumed that it had been planned, to a certain extent, to save the expense of carrying the work to the top of the flood water, and of forming a tumbling over-fall. If his assumption was correct, the series of cylinders would perform a separate duty in controlling any breach that might occur in the surface. Again, when the water was flowing over at the flood level, that duty would be reduced to a minimum.

In conclusion, he would suggest to the Author that he would confer great benefit upon the Students of the Institution if he would follow up this interesting Paper by accompanying it with

more complete engineering details and by general sections of some of the main arterial canals. A series of such documents would add greatly to its value.

Mr. G. B. Bruce said there was considerable difficulty in discussing the Paper, owing to the incompleteness of the engineering details. As regarded the Okhla weir, there was no information given as to the water levels of the river. It appeared that the bed of the river was of fine sand; and it might be that the low water at certain seasons was just level with the top of the bed, or—as was often the case in Indian rivers—that the low-water level was below the bed. If such was the case, it seemed strange that the cross-walls should not have been sunk below the bed of the river; and under any circumstances, it seemed rather a hazardous experiment to build the centre walls without putting wells under them, or sinking the foundations to a greater depth than had been indicated by the Author.

It had been stated that the slope of the upper section of the apron in the Rājghāt weir was proposed to be only 1 in 4; it was, therefore, a matter of surprise that there was no protection to the 'toe' of that slope, however much such protection might not be required in the lower portion of the apron, carried as it was to such an extent that its formation simply amounted to tumbling in large stones for a great length along the river bed. The entire structure, as proposed by the Author, seemed peculiarly venturesome. The upper row of brick cylinders as well as the lower one ought to have been carried down deeper, on to the clay stratum, to which level, it had been stated, scour occasionally took place during floods. If this was not done, he should expect to see the upper wall fail, resting as it did on shifting sand very liable to scour under the most ordinary circumstances. He did not consider the weir would be safe with the upper cylinders carried down to so shallow a depth; and he thought that it would have been wise and economical to have carried them to the same depth as the lower walls, thus converting them into two cross-walls, and filling the interval with concrete, protected with stone above, and below at the 'toe' of the slope. If built as proposed by the Author, he believed that in a heavy flood the upper walls would be scoured bodily out and carried over the lower line of walls, which, in their turn, would be swept away in the general destruction.

With regard to what had been said about the rate of interest which was returned to the Government by irrigation works in India, he was glad to hear that they were so productive as to lead the Government to carry them out to so large an extent; but still

he took with great hesitation the account of the actual cost of Government works. He thought in India generally that the public did not know exactly the cost of public works: that was, they did not know what was put into the estimate, and what was kept outside of it, or what were the general charges of the military officers and other persons in supervision, whose time and expenses did not form an ingredient in the work. If he recollected aright, there was some Mahomedan work, which was stated to have returned a clear profit of two millions; but it did not appear that any one knew what it originally cost; and, consequently, any estimate of the percentage of profit returned must be a pure assumption. There was a great difference between the manner in which Government accounts were kept and those of a joint-stock company. In the latter case, everything, including all general charges, was placed to the account of the works constructed.

Mr. BALDWIN LATHAM observed, that the Paper was one of considerable interest and importance, as showing the extent to which irrigation works had been developed in India. Apart from the great agricultural results obtained from irrigation, it could not be overlooked that, with the extension of the works, sickness and death had been materially increased, especially in districts in which certain processes of irrigation were carried on. It was well known in India, Egypt, Piedmont, Lombardy, and Southern France, that such irrigation as was brought into operation in the cultivation of rice, developed or augmented a certain class of disease; while, on the other hand, irrigation, by a different method, or in which the irrigated meadows were arranged with sloping surfaces, as in the cultivation of marcite, no baneful results had followed; hence, laws and regulations had been introduced into many countries restricting the cultivation of rice to certain distances from populous places, but permitting other descriptions of irrigation to be carried on in their immediate vicinities. In the year 1845, a Commission was appointed by the Governor-General of India, to inquire into the cause of the unhealthiness of certain irrigated districts. That Commission was also required to report upon the probable effects of the introduction of irrigation, in the district described in the Paper as lying between the rivers Ganges and Jumna. The results of that investigation were recorded in Capt. Baird Smith's "Italian Irrigation,"[1] and the conclusion then arrived at distinctly pointed out that in the districts "under the influence of the existing canals, sickness had been

[1] *Vide* "Italian Irrigation," by R. Baird Smith, F.G.S., Captain of Engineers Bengal Presidency. Edinburgh and London, 1855. Vol. ii., p. 359 *et seq.*

largely developed." The Commissioners, however, pointed out that this was in a great measure due, not so much to the results of irrigation, as to the fact that the natural drainage of the country was impeded, and tracts of swampy land created which diffused a malarious influence around.

In the cultivation of rice, the system adopted was that of surrounding the irrigated plot by a small embankment, turning the water within the enclosure; and, as a rule, such water had no chance of escape except by evaporation through the rice-plant or from the water surface. Irrigation works laid out with surface slopes, and a current of water flowing over the surface, prevented that stagnation which, in the case of rice, had been shown to be detrimental to health. What were the precise differences of the application of water in rice irrigation and those in irrigation works, where a constant current was kept moving, he had made a subject for investigation, and would proceed to give the results of some experiments, which would show that where a surface velocity was created, that velocity would promote a circulation of water through the soil, a matter of no small importance, as by that circulation manurial matters were equally distributed, while other matters, not required by the plant, were removed, which, if allowed to stagnate, produced those ill-effects shown when cultivating rice. He had been led to undertake those experiments in consequence of having observed in sewage-irrigated fields, that if sewage was placed on a field laid out with surface slopes, and the field was perfectly saturated with water, as in time of heavy rainfall, the sewage displaced the rainfall which had saturated the soil, taking its place; and that subsequently it appeared that each increment of sewage passed on the surface of the field displaced the previous increment, and so a circulation of water was carried on through the soil. In order to put these views to the test he had constructed a water-tight glass tank, 5 ft. long, 12 in. deep, and 6 in. wide. The tank had then placed in it a solution of perchloride of iron of the specific gravity 1·027. It was then slowly filled with fine silver sand, and after being allowed to rest for some time in order to obtain perfect solidification of the materials, the tank was placed at an inclination of 1 in 100. An infusion of nut-galls of the specific gravity of 1·002 was allowed to pass slowly on to the tank, at its upper end, the infusion being dropped into a small metallic trough, laid across the glass tank so as to prevent the disturbance of the surface of the sand by the passing of the infusion of galls on to it.

In Fig. 1 the point T showed the position of the trough receiving the infusion of gall. The two liquors used were adopted on account of their mixture forming a tannate of iron, or ink, which portrayed a perfect diagram at every stage of the experiment. The light lines showed the effect produced by the infusion of galls after each 24 hours' experiment, and the total quantity of solution passed from the commencement of the experiment. It would be seen that by natural gravity the infusion of galls could not be passed to a greater depth than 0·6 in., at the upper end of the tank, and that gradually the depth diminished to nothing at the lower end. After 48 pints of infusion were passed on to the tank the infusion reached the bottom of the tank, and from the direction of the curved lines it was natural to infer that, had the tank been deeper, a greater depth would have been reached. What was singular in the case was that the light gall solution which displaced the iron solution for the space above the lines, marking the point of contact between the two liquors, was found to contain an infusion of galls; and, until the black lines marking the junction between the two liquors reached the lower end of the tank, nothing but a pure uncoloured solution of iron came off, equal in quantity to the gall solution passed on. At the end of the ninth day, instead of an infusion of galls, a solution of perchloride of iron was passed on to the tank. The three dark lines showed the effect produced in those days by reversing the order of the liquors which had been used, and again producing discoloration at the point of junction between the two liquors. This was corroborative of the displacement of the former liquor occupying the interstitial place in the sand. It would be seen that the

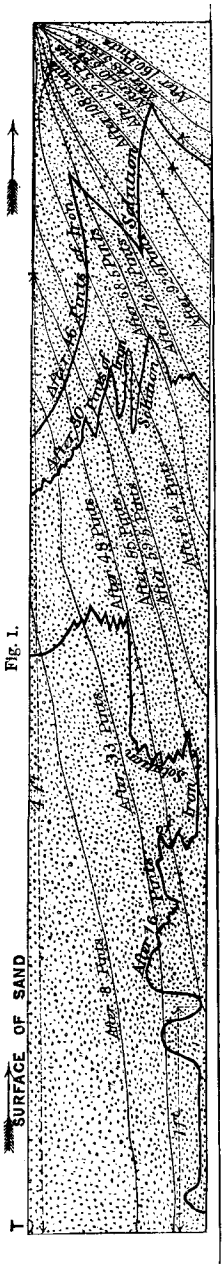

Fig. 1.

CIRCULATION OF WATER IN THE SOIL.

displacement was much more rapid when a solution of greater specific gravity was used to displace an infusion of less specific gravity. During the three days the iron solution was passed in, it had the effect of driving forward the former infusion of galls in the sand; for, as the three dark lines were being produced, the three light lines marked + + + were also formed. The last two light lines were formed by simply passing water on to the upper end of the tank, which had the effect of pushing forward the infusion of galls. A number of experiments were also made, with different materials, all of which went to show that where there was an inclination of surface or the productions of natural currents over the surface, a circulation through the soil took place.

While these experiments were proceeding another tank was prepared giving the conditions of a rice-irrigated field. In this the sand was saturated with a solution of perchloride of iron, and an infusion of gall passed on to the surface; the tank was kept level, and there was no inclination of the surface and no motion in the liquor over the surface; and it was found that after six months' contact, discoloration of the sand had not taken place to a greater depth than 0·25 in., showing that there had been no displacement of the water occupying the interstitial space in the sand. What could be the precise cause of these results, except circulation, it was difficult to conceive. It might therefore be assumed that when there was no motion in the liquor over the surface there was no penetration into the soil; but that by an inclination of surface producing a current, however small, that current appeared to have the power of putting in circulation the water occupying the interstitial space of the soil. The curved lines in Fig. 1 represented the different rates of velocity within the interstices of the sand, at various depths from the surface. For example, at the end of the third day it would be seen that, while the water had flowed 4 ft. through the surface of the sand, it had only flowed a distance of 1 ft. at the level of the bottom of the tank; showing that the velocity of the surface was 4 times that at the bottom of the tank. From these experiments he had drawn the conclusion, that rice irrigation differed from ordinary irrigation, where the fields were laid out with slopes so as to create a velocity of the surface, as much as a stagnant swamp can differ from a running stream; and he thought that they further demonstrated that, if it was possible, by any means, to establish such a system of irrigation in the cultivation of rice, whereby a circulation of water could be promoted

through the soil, that class of irrigation could be deprived of its noxious influence. The circulation of water through the soil, although never to his knowledge previously established, had a marked beneficial influence on irrigation works, as conclusively shown from the practice adopted for generations in the irrigated districts of Piedmont and Lombardy, where it was customary, as the head-water was left, to increase the natural slope of the irrigated beds, in order to create a greater velocity, and hence a greater circulation through the soil. He might also add, that even rain falling upon the surface of a field having a considerable slope would produce a circulation through the soil; for it was found that an infusion of gall, admitted on to the glass tank, at several points formed a series of curves very similar to cycloidal curves, and that the iron solution was driven out at the lower end of the tank.

Mr. W. SHELFORD said that he had in his possession a longitudinal section of the river Nene at Sutton Bridge, taken in July, 1847. At that time the present bridge had not been erected, but an older structure occupied its site, and the bed and sides of the river—of sand and silt—having been scoured away, it had become necessary to protect the foundations of the bridge by throwing in stones. At the time the section was taken the stones so thrown in had formed a weir, of a rough character, across the river to the height of some 7 ft. 6 in. above the normal bottom. The river Nene was a tidal river, and at high water of spring tides there was a depth of about 21 ft. over the weir, and at low water of spring tides a depth of about 3 ft. 6 in. The difference of level between the surface of the water on the upper and lower sides of the bridge was about 1 ft. at low water. At a distance of 300 ft. on each side of the weir there was a deep hole, which was 23 ft. below the normal bed, giving on each side a slope of about 1 in 10 from the summit of the weir. At a distance of 600 ft. on each side of the weir the new bed remained undisturbed. The total distance between the two extreme points where disturbance took place being about 1,200 ft.

Mr. J. G. C. C. GODSMAN considered that the necessity for irrigation works was unhappily too well known to all acquainted with India, each and every one of whom must have often heard the terse but truthful phrase, "Irrigation is life-blood." If the self-constituted rulers of that country did not take care that a sufficient quantity of water was stored up and supplied to the natives, they were responsible for the lives lost by famine. As the question stood at present, it was the duty of engineers to consider how they could most efficiently and economically design and con-

struct works which should—by contributing to their future happiness and prosperity—in some measure, recoup the toiling millions for the fearful amount of taxation which, under British rule, had been exacted from them without adequate return.

The Paper was certainly not one from which much could be learnt by the Students of the Institution who were preparing for Indian appointments. It appeared for the most part to be composed of geographical, meteorological, and statistical extracts, of comparatively little use to those whose duties for many years would necessarily be confined to executing and superintending subordinate works. It was true that some scanty details had been given of the weir in course of construction at Okhla, and of another proposed at Rājghāt. But so far as could be ascertained from the imperfect information before the meeting, both of those models were rather to be avoided than imitated.

About thirty years ago he was employed under the East India Company upon the irrigation works of the Madras Presidency. At that period, with the exception of the Colleroon Annicuts and the works in connection with them, no extensive irrigation works had been undertaken by the Company; and indeed those which had been previously constructed under the native rulers had, in numerous instances, by an unwise economy, been allowed to fall out of repair, and hence into desuetude and decay. It was a melancholy fact that as lands previously watered had been reconverted into jungle whole districts had become deserted and depopulated. The comprehensive accuracy of design exhibited in the more extensive native works, and the thorough economical adaptation of the minor constructions to the several objects in view, showed that the natives must have formerly possessed a thorough practical acquaintance with the leading principles of fresh-water hydronomy. Their clear appreciation of the relative importance of the primary elements of time, height, and volume was strikingly displayed in the accurate manner in which they had determined the exact character and class of works necessary to meet the peculiar exigencies severally involved. Scarcely any changes were required in the levels of the larger channels which they had designed, and their works, although constructed of the most economical materials, had lasted for centuries. A well-known instance of the durability of the native works was afforded in the case of the Grand Annicut, or weir, at the seaward extremity of the island of Seringham. That weir was 1,800 ft. in length, from 40 ft. to 60 ft. in breadth, and its crest was from 15 ft. to 18 ft. above the level of the adjacent bed of the river. Although

only built of rough stones of moderate size set in clay, it had withstood the effects of the floods for 1,600 years, a period at the expiration of which few engineers of the present time could reasonably hope their works would exist.

When he was employed in the Madras Presidency there were several systems adopted for dealing with the scour produced by the overfall water from a weir. Some weirs were simply built of rough stones, and others had masonry or brick dams with short masonry aprons, the entire structure being based on foundation wells. In those cases rough stones were from time to time tumbled below the crest of the weir or at the termination of the apron, until experience showed that a sufficient number had been thrown in to counteract the effect of the scour. Another mode was to construct a masonry apron of a greater length, in which upright stones were sometimes placed to 'break' the fall. In some weirs the apron was divided into a series of steps with the same object in view, while in others hollows, or a series of hollows, were constructed in brick or masonry, so that the reservoirs formed should act as a kind of water cushion, and these were occasionally filled with rough stone so as further to break up or distribute the force of the fall.

At that time there was a great divergency of opinion as to the precise forms to be given to weirs. The natives contended that to deal economically and successfully with water, it was only necessary to study the operations of the Great Engineer of the universe, and hence, that the forms adopted for artificial works should as nearly as possible be those by which the desired effects were naturally produced by the action of water. Hence, nearly all their weirs were designed in curves, or a series of curves, in greater or less imitation of the forms assumed when water crossed a natural shoal or hard in the bed of a channel. On the other hand, the Madras Engineer officers for the most part rejected this theory, and adopted straight, level, and perpendicular outlines in their constructions. One of the advantages possessed by the native system was, that the curved surface of the crest of the weir allowed the water to pass over more easily; while the central depression, or depressions, insured a greater degree of uniformity and permanence in the deep-water channels into which the broad beds of sandy rivers with small falls were apt to be divided. Another advantage possessed was, that owing to the greater velocity at the depressed portions of the weir, the sand and silt brought down from the up-country were passed over the weir instead of being allowed to accumulate in the bed of the river

on the up-stream side. The practice of the Madras Engineer officers was to construct under-sluices in the body of their weirs in the hope of attaining a like result, but he might safely say that during his experience in the Madras Presidency he had never seen an under-sluice in a weir that had effected the object with which it had been erected, namely, that of keeping the bed of the river above the weir free from accumulations of sand and silt. The under-sluices in the Colleroon Annicuts were a notable illustration of the general correctness of the native views. The under-sluices in both of these works had proved a complete failure, and in the case of the Upper Annicut it had become necessary to revert to the native practice by lowering a portion of the body of the work so as to make a central depression of 700 ft. in width and 2 ft. in depth. He made these special criticisms with less reluctance than he otherwise should have done, because—in their financial and general results—the Colleroon Annicuts had unquestionably proved one of the most remarkable successes on record. None but those who, like himself, had been employed in the district could form an idea of the blessings which they had conferred, or rightly estimate the gratitude and esteem in which the memory of their talented projector, Sir Arthur Cotton, was held by the inhabitants. To the moral energy and persistency of that officer it was mainly due that sanction was obtained for the first large expenditure, under British rule, for irrigation works in India. In these days of facilities of transit and rapid communication of ideas, it was difficult to realise the extent to which the Madras Engineer officers, at that period, had to rely upon their own resources, or the disadvantages consequent upon the comparative isolation from professional intercourse and assistance in which they were placed, and under which they had to discharge their onerous duties.

Colonel MEDLEY, R.E., had seen the Okhla weir while under construction, and certainly had thought it a very bold piece of engineering; but he understood it to be an attempt to apply the Madras system of construction to a stream in Upper India. He understood that system to be a shallow foundation with a long talus of loose stone on the down-stream side, which was repaired and replaced by fresh stone as fast as it was undermined and disturbed by the scour of the river. In Bengal, on the other hand, the foundations were carried to a great depth, often to 60 ft. or 70 ft., until firm soil was reached. The difference in practice he had understood to arise from the presence of stone in the one case and its absence in the other. Bengal Engineers, as a rule, had nothing but brick to work with; but, as there was plenty of stone at Okhla, the Madras practice had been followed.

At Rājghāt, he believed, there was no stone. The mode of construction proposed for the weir at that place seemed hazardous. He should certainly fear a dangerous scouring action at the 'toe' of the down-stream slope.

He had been for four years in charge of the Indus Inundation Canals, of which a slight description might be interesting to the Meeting. They were for the irrigation of what was called the 'khadir,' or bottom-lands of the river, and were simply cuts from the parent stream, generally parallel to its course. They were filled with water when the river was in flood, and emptied again in the cold season, when the river was low. Advantage was then taken of the subsidence of the water to clear out the silt deposits of the channel, in readiness for the next rise. They were thus only useful to the 'khurreef,' or autumn crop, the less valuable of the two; but, owing to the very scanty rainfall of that part of the country, seldom exceeding 4 inches or 5 inches annually, they were of great importance to the cultivators.

As to the perennial canals, which were the more immediate subject of discussion, it had always seemed to him that sufficient attention had not been paid to a better mode of selling the water to the cultivator than the present system of measuring the irrigated land, and charging water-rate by crop and area. He had always thought that the water should be sold, like beer or wine, by measurement, and that any interference with it after it had been delivered at the distributory head was an expensive and meddlesome system, which drew away the engineer from his proper duties, to business which more properly belonged to the revenue authorities. He was quite aware that there were difficulties in the invention or application of a satisfactory module, arising chiefly from the inequality of supply in the main canal, and therefore of the head of pressure at the irrigation outlet, as well as from the want of available fall at this latter point. But he believed those difficulties had been exaggerated, and that any system which gave even a tolerable approximation to fairness would be preferable to the present. In this opinion he was supported by Colonel Fife, the Chief Engineer of Bombay Irrigation, and by other engineers, though he was aware the canal engineers of the North-Western Provinces were generally opposed to it as impracticable.

It also appeared to him that more attention should have been paid to the importance of navigation canals in Upper India, a subject which had only lately received serious attention. He was aware of the great, perhaps the insuperable, difficulty of rendering irrigation canals properly navigable under the conditions that

obtained in Northern India; but the importance of cheap water-carriage in a poor country like India, and for bulky articles such as grain, could scarcely be overrated. He did not see the great benefit to be derived from indefinitely increasing the productive agricultural area of a country, unless equal facilities were given for the cheap carriage of the produce. In many countries which are exceedingly productive, the condition of the cultivator was anything but satisfactory. Low wages and low prices, in fact, had always meant poverty all over the world, and always would mean it. He did not undervalue irrigation in saying that it was not the panacea its friends often represented it to be.

He remembered the late Lord Elgin remarking, when he saw the Ganges Canal, that having been in America, he could not help feeling what a pity it was that all the water-power at the various falls should be running to waste. Colonel Medley would like to see the time when English capital, which was expended all over the world, should be applied in that direction, so that great manufactories might be established along that magnificent stream. Meanwhile it was desirable that cheap water communication should be obtained as quickly as possible, so that the whole population of fertile districts should not be employed simply in raising their daily food. With cheap water communication, the failure of the crops would not be the irretrievable misfortune it now was.

Mr. BRUCE inquired whether the cross walls of the Okhla weir were founded upon the normal bed of the river, or were sunk below it?

Colonel MEDLEY replied, they were founded upon the normal bed of the river, not sunk.

Mr. BRUCE remarked that the ordinary practice in the Madras Presidency would have been to have sunk the wells 6 ft. or 10 ft. below the normal bed of the river, and then to have built the walls upon them.

Colonel SMITH said that it was quite true that, as Mr. Bruce mentioned, the Madras practice would have been to sink wells filled with rubble, and to build the walls upon them; but he thought the use of the walls in the Okhla weir was not properly understood. Objection had been made also to there being no foundation to the 'toe' of the dam, both in front and rear. He would point out, with regard to the front of the wall, that a foundation was not found to be necessary, for, instead of the soil being carried away, there was an accumulation, and the whole river-bed gradually filled up, till it reached the crest of the weir. There was, therefore, no occasion for protection to the front wall,

or slope. With regard to the rear slope, which was a very long one, it was found that the stones at the end did sink during floods, and as often as they sunk their places were filled up again and again, so that, in the end, a good foundation was secured.

Then, as to the use of the walls. It was found that the great force of the stream in floods often lifted even large stones, and carried them bodily down the slope, so that, if there were nothing to prevent it, the whole of the upper part of the weir would be carried away; consequently, it was found necessary to construct cross walls, to prevent the stones traveling. They were not intended to resist the scour, which was prevented by the front wall and slope.

With respect to the interest upon the capital expended upon the works, Colonel Smith could not vouch for the accuracy of all the statements which might have been put forth, but he remembered on one occasion being permitted to see the accounts of the Ganges Canal, which was unsuccessful for many years, and he was struck with the faithfulness with which every farthing was debited against it. He was happy to learn that the works in the North-Western Provinces paid 6 per cent. upon the capital; but he did not know whether, in making these calculations, the salaries of all the engineers were charged against them or not. He was inclined to believe they were.

With regard to rice irrigation, he himself was a witness that it was not necessarily unhealthy. His son, now present, was born in the midst of it; for at that time Colonel Smith's family occupied a house in the centre of a large area of rice fields, and the same house had been inhabited for years without the least thought of unhealthiness. He believed, if the rice were properly drained, there would be no inconvenience from malaria; certainly neither he nor his family ever suffered from it. If, however, the drainage were neglected, or only half done, the result might be different.

With regard to under-sluices, Mr. Godsman had remarked that "he had never seen an under-sluice in a weir that had effected the object with which it had been erected, namely, that of keeping the bed of the river above the weir free from accumulations of sand and silt." Colonel Smith must, with great deference, say he never now heard of under-sluices which did not answer their purpose. But that was not to keep clear the bed of the river, but the mouth of a supply channel. It was useless to attempt to clear the bed of the river, but it was absolutely necessary to keep the mouth of the irrigation channel clear, and that was done by the under-sluices.

A remark was made about the works of the Grand Annicut having

been in existence 1,600 years; and what a lesson it afforded, compared with the works of modern engineers. It was true that the Grand Annicut continues to this day, but the authors of it never considered the question of pounds, shillings, and pence, and it is all the more creditable to modern engineers whose works endured, in which that very important consideration had been attended to. When Sir Arthur Cotton, who was the founder of the modern system of irrigation in Southern India, first went there, it was to repair the defects in the Grand Annicut; and, in doing that, he originated the system which was the glory of Southern India, and a benefit to the whole empire.

Then, something was said about time and height. He believed one of Sir Arthur Cotton's suggestions led to a considerable change in the previous system. In the early days of irrigation, the native plan was to make a channel at such a height in the bank of the river that, when the river rose to that height, the channel was filled, and, when the river went down, the tanks were left full; but it must be observed that sometimes the river never rose to that height, and then the tanks were not filled. That was the defect of the native system. By Sir Arthur Cotton's plan the dam raised the bed of the river, and adjusted the level of the flood to that of the channels, so that they were always filled. That was the difference between the ancient and modern systems, and he thought the latter had the best of it.

With reference to the measurement of water—the Government of India had expressed a desire to have the means of measuring water on a large scale by an apparatus which would be simple and easy of management. He was glad to say there was already a simple method of doing it. An instrument made for another purpose had been accidentally found to possess the property of delivering equal quantities of water in equal times, under any head, and thereby of measuring the quantity of water passing through it. The instrument was very simple, cheap, inaccessible, and, when properly fixed, not liable to get out of order.

Mr. GODSMAN said, that whatever differences of opinion there might be as regarded the efficacy of the under-sluices, it was desirable that those studying Indian irrigation should clearly understand that they were originally placed in the Colleroon Annicuts with the object of keeping the bed of the river above them free from accumulations of sand and silt. As the contrary might have been inferred from Colonel J. T. Smith's remarks, he would take the liberty of reading some extracts from the Transactions of the Madras Engineers, of which that officer was the editor. In a

Report on the Colleroon Annicuts, Colonel Duncan Sim, the Inspector-General of Irrigation Works, said:—"There remains another objection to be considered which I have not heard stated, but which appears to me to be of more weight than any of the preceding. It is the difficulty to be apprehended in preventing the bed of the Colleroon above the annicut from being raised to a level with the top of the work, or nearly so, by the sand and mud in its passage down the river. If this should happen, it is manifest that the bed of the Colleroon being raised at the point of separation several feet higher than that of the Cauvery, a much larger portion of the mud and sand will be carried into the latter river than can be discharged by the under-sluices or into the sea through the mouth of the river. The object of the annicut is to raise the water, preserving the bed of the river at its present level; for if the bed is raised, the remedy, like all former expedients, will be temporary.[1] . . . . To prevent this evil, a certain number of under-sluices have been constructed in the annicuts, but these are apparently not of sufficient power, for the bed of the Colleroon at both annicuts has already been very considerably raised."[2] And, again, in a subsequent portion of the Report, reverting to the subject, he said:—"In considering in a preceding part of this Paper the objections which have been urged against the annicuts, I have adverted to the difficulty of the gradual deposition above it of the mud and sand brought down by the river in its gushes, and the ruinous consequence which would follow any considerable rise in the bed of the point of separation from its sister stream. The evil was not overlooked by Captain Cotton, who provided for its prevention seven sluices, as already described, distributed along the annicut, having in all twenty-two vents, each about 2 feet in width and 2½ feet in height. But these are evidently inadequate to the purpose, and are far from being sufficiently powerful to regulate the bed of a river 750 yards wide, having a rapid stream 12 or 14 feet deep in high floods. On such a volume of water, bringing down a large quantity of earthy matter from the mountains, twenty-two small openings can scarcely be expected to exercise sufficient influence. The nature of the deposits also increase greatly the difficulty of their removal. They do not consist entirely of sand or gravel, but contain a considerable portion of fine clay and soil, which, as it dries, hardens and forms, with the sand, a mass almost impervious to water, and requiring the influ-

[1] *Vide* Transactions of the Madras Engineers, vol. i., p. 142.
[2] Ibid., p. 143.

ence of an extensive and rapid stream to displace it. The accumulations above both are already very considerable, and in some parts not far below the top of the works."[1]

In his Report on the Irrigation of Southern India, Colonel Baird Smith had also stated that there were twenty openings or sluices in the Upper Annicut, and that the object with which they were constructed was "to effect the passage of the sand, and, if possible, to prevent the bed of the Colleroon above the dam being raised by deposits."[2] And he further stated that they had proved ineffectual, and that, at the time of his visit, the bed of the river above the dam was on the same general level as the crown of the work.[3]

As regarded the question of navigation, it might be interesting to know, that in the Madras Presidency it was the custom to bring the produce from the upper country down the rivers, irrigation channels and canals in wicker boats covered with hides—the downstream favouring their voyage—and that, when discharged of their load, they were taken to pieces, and carried back by bullocks. He did not consider rice cultivation was necessarily unhealthy if proper precautions were taken as regarded the drainage; but in all tropical and semi-tropical countries he had found that when the water first entered the dry channels, and moistened and stirred up the decayed vegetable matter, a certain amount of endemic disease was inevitable.

Colonel SMITH said, that he had expressed a different opinion from Mr. Godsman on one point, which he still maintained. He said that under-sluices in an annicut were not now made to maintain the bed of the river, but only to keep clear the mouth of a supply channel. Colonel Baird Smith himself stated that the under-sluices in the annicut referred to were useless to keep clear the bed of the river.

With regard to the Colleroon, he said it occupied the same position in regard to the Cauvery as a main river does to a supply channel, and the object of the under-sluices in the bank of the Cauvery was to discharge any surplus water from that river into the Colleroon, which was at a lower level; but it was found that there was no means of regulating the bed of the Cauvery except by the construction of a demi-annicut, or wall, across its mouth at the point of separation. What he stated was that the object of under-sluices was, not to keep the bed of the river clear, but only to keep clear the mouth of the side channel, which was the channel for leading off the water for irrigation.

[1] *Vide* Transactions of the Madras Engineers, vol. i., p. 144.
[2] *Vide* "Irrigation in Southern India," p. 18.
[3] Ibid., p. 20.

Mr. RUSSEL AITKEN expressed his concurrence with the views of Colonel Medley as to the desirability of selling water for irrigation by actual measurement of the water supplied, but thought there were many difficulties in the way of doing it, as the Hindoo cultivators were very cunning in seeking means for evading payment. He was the only engineer in India who had sold water for irrigation by meter, and it was impossible to conceive the innumerable methods that were practised to evade payment for all the water consumed. Therefore any means invented for measuring water must be exceedingly simple, and at the same time incapable of being tampered with.

The proposed mode of constructing the weir at Rājghāt was quite different from what was originally proposed by Captain Jeffreys; and looking at the construction generally, and the mode in which it was proposed to put in the tail slope, he did not think it practicable to make a permanent work in the manner described. As the level of the water in the river was much higher than the country on one side of it, the danger of causing the river to take a fresh course must not be overlooked.

Mr. HAWKSLEY, President, regretted that the Author was unable to attend to reply upon the discussion. The Paper was really a valuable one. If time had permitted he would, on behalf of the Author, have made a few observations upon some of the principal points which had been discussed; but the hour for adjournment had arrived, and therefore he had not the opportunity of doing the Author that justice which otherwise he should have felt himself obliged to do on the occasion of his enforced absence.

January 21, 1873.

T. HAWKSLEY, President,
in the Chair.

The discussion upon the Paper, No. 1,350, "On the Practice and Results of Irrigation in Northern India," by Colonel W. H. Greathed, was continued throughout the evening, to the exclusion of any other subject.
