Mr. Hill. were hardly complete and definite enough to put into a periodical or a Paper for the Institution. They carried conviction rather by their number, and there were many now known to waterworks-engineers. Perhaps to people who were not aware of the circumstances, and expected the precision of a laboratory experiment, they might not carry the same weight as they carried with waterworks-engineers. As to the general question, of course if the matter were to be taken up by Government it might mean a long delay; and although the work might be done when the nation had more money to spend, yet in the meantime if a start could be made at only ten, twenty, or thirty places in the hands of thoroughly competent resident engineers, some very valuable information could be obtained. When the discussion was published in the "Proceedings" of the Institution, many engineers who were in a position to make such observations might really take the matter in hand, and that would be, perhaps, the most valuable result of his Paper. Of course engineers in Westminster, after they had constructed waterworks, usually lost sight of them altogether until they were called in to make extensions, and therefore they had no means of making observations, and experiments which might have been made were not made.

The President. The PRESIDENT, in reply to Mr. Thrupp, said he was afraid it was not competent for an ordinary meeting of the Institution to pass resolutions with regard to Committees or matters of that kind. They had to be dealt with in another manner.

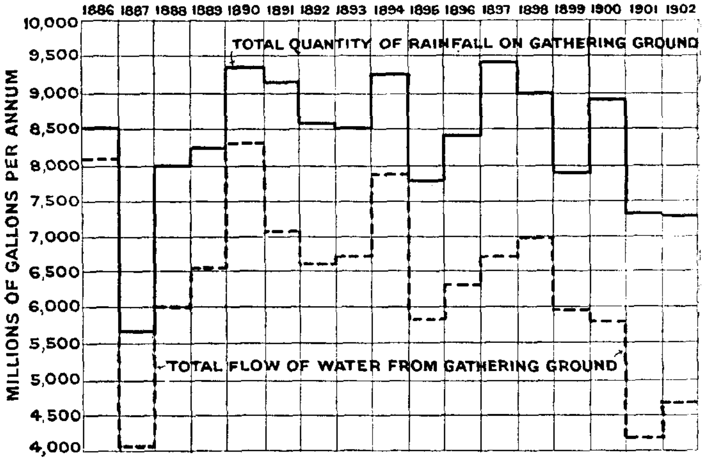
Correspondence.

Mr. Barr. Mr. JOHN BARR, of Kilmarnock, communicated the following notes on the outlet-works of the Talla reservoir:—The sockets of the branch pipes of the inner tower were cast on the cast-iron plate lining of the towers, opposite the branches on the inner cast-iron stand-post; and a pipe was fitted in and run with lead joints, this pipe being made in each case to a wooden template after the inner post was erected in position. This closing pipe was in the form of a bend. The screw headstocks had bronze spindles working through gun-metal nuts inside a cast-steel worm-wheel, into which a wrought-steel worm was geared. Each of the copper tubes conveying power-water to the hydraulic cylinders for operating the sluice-valves was furnished with a stop-cock, in addition to the four-way operating cock, so that any one could be isolated for examination. Each of the two supply-pipes was furnished with a stop- and check-valve, so that in the event of any accidents to one supply-pipe the check-valve kept the other one charged. The lower casting of the stand-pipe was 5 feet in diameter and of 2-inch metal, and external ribs were carried down from the top flange to the bottom flange of the casting, to compensate for the weakening effect of the three 36-inch branches, as this bottom casting had to sustain the whole weight of the upper portions. A tapered pipe intervened between this lower casting and the upper parallel portion, which was 48 inches in diameter. The lower casting was provided with a 36-inch gun-metal expansion-joint, placed between the bottom casting and the two 36-inch valves on the supply-pipe; so that the valves could at any time be removed if necessary, without breaking the pipe. Perhaps the most unique part of the structure was the sluice-valves, which were made entirely of gun-metal, as mentioned in the Paper. He believed the reason for this was the serious corrosion which had occurred in the valve-tower of Gladhouse and Rosebery reservoirs. In 1891 or 1892 one of Messrs. Glenfield and Kennedy's men was sent to examine the lower sluices in these towers. The Gladhouse one was found to be in a very bad condition. The water came through the masonry of the tower so freely that the man, clad in oilskins, had great difficulty in making the needed repairs. Both sides and rungs of the ladders inside the tower were completely rusted through near the bottom; indeed, the ladder broke, and the man fell some distance. The sides were of iron about 2½ inches by ⅜ inch. The lewis-bolts fixing the sluice-frame to the wall were eaten away and had to be replaced by brass bolts staved with cold lead. The cast-iron was also so much deteriorated that it could be easily scratched and cut with a knife. The man had to stand in 2 to 3 feet of water at the bottom and had great difficulty in making repairs. The gun-metal faces on the sluice were quite good so far as corrosion was concerned, but had been wrenched off the cast-iron door, evidently through the softness of the cast iron after being subject to the action of the air and water. Mr. Barr understood that the sluice had been fixed about 20 years previously. He considered that the engineer had been wise in providing a cast-iron lining for the inner tower at Talla, in which the ironwork could be cleaned and painted at any time. At Gladhouse this was impossible; indeed, so much water came through the masonry that the man could hardly work for the weight of water falling on him. Mr. Barr.

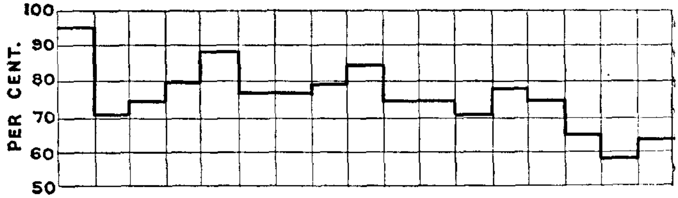
Mr. WILLIAM B. BRYAN mentioned that about 20 years ago he put down a stream-gauge for the purpose of recording with great accuracy the yield of a gathering-ground of 6,000 acres. The weir Mr. Bryan.

Mr. Bryan. and gauge-basin were constructed of considerable size, and so as to measure both large and small flows with accuracy. The rainfall and flow in this area from 1886 to 1902 were shown in the accompanying

Fig. 4.



TOTAL ANNUAL FLOW OF THE RIVER, AND TOTAL AVERAGE ANNUAL RAINFALL



RATIO OF TOTAL DISCHARGE TO RAINFALL ON GATHERING-GROUND

diagram (*Fig. 4*). The gaugings of the stream were continuous and were recorded on a diagram, the vertical scale being one-half the actual height on the weir.

Mr. Clark. Mr. Alexander Clark remarked that, from the amount of patching that had been going on for 3 years in the Hutton Roof aqueduct it would appear that the face of the concrete had been damaged from a very early period of its history. Once a passage had been established the leakage would rapidly increase, more especially as the stone was so liable to be worn away when placed in a current of water. Mr. Barnett did not say that any efforts had been made to check currents of water running in the tunnel outside or through the concrete lining, either above the roof, or along the sides, or below the invert. If there were such currents, they would

Mr. Clark.

not be increased by any escaping water from the aqueduct after the remedial works were finished, but if there was still any porous concrete behind which had not been repaired or patched up the water might still be wasting away the stone—though at a diminished rate—and thus decreasing the strength of the backing and the lining of the aqueduct. Besides the inside plastering, it might have been well to remove the concrete lining altogether in certain places and to replace it with fresh, sound material, so as to prevent the possibility of a wasting current running behind the walls. There was no doubt that it was not easy to make concrete thoroughly water-tight, but in the lining of an aqueduct it was no doubt the intention that this should be attempted and, in a particularly open bottom, such as loose-jointed limestone constituted, it seemed almost necessary that some special precaution should be taken. In 1867 a covered reservoir was formed at Blackhurst for Tunbridge Wells waterworks. The walls were of brick and the floor of concrete, both faced with gault bricks (said to be impervious to water), but notwithstanding this, there was difficulty in making the reservoir water-tight. The walls and floor were admitted to be as strong and perfect as could be constructed, but the arbitrator decided that there was a want of water-tight material around them. Mr. Barnett suggested that the soft water from Thirlmere dissolved the limestone of the concrete but had no effect on the mortar which formed the matrix surrounding the stony material. But almost the first question that occurred to the reader was—Why was the matrix washed away in the cases mentioned, and why was the water allowed to enter the concrete and form a conical-shaped funnel at one place and an enlarged cavity of 4 cubic yards' capacity in another? One clue was afforded in the Paper (p. 173), where it was mentioned that "all the walls had been built for a considerable time, and had become well set and hard, before the invert was done." Now, although it might sometimes be convenient to leave the construction of the invert to the last, it was very undesirable for the work, as the Author admitted. If there was any leakage it was almost impossible for it to escape observation when the invert was laid down before the side-walls were built. The analyses of the two samples of water were so nearly identical that if any of the lime had been absorbed by the water it must have disappeared in the leakage. There had evidently been a very strong current through the concrete, but this could only have been after the matrix had been washed away. Presumably all the six sides of the cubes of limestone had been exposed to the action of the water, and they might have been rolling about in the wells and undergoing waste by friction with the sides

Mr. Clark. of the well. Had these stones been embedded in the concrete, only one side or perhaps only a portion of a side could possibly have been exposed to the action of the water, and quite likely the matrix of mortar would have covered the whole. Therefore, taking the amount of waste of the limestone given in Table VI as varying from 6 to 12 per cent. for all the six sides, the waste on one wholly exposed side would not exceed 1 to 2 per cent. per annum. It was very unlikely that anything approaching this rate could possibly represent the action on the wall or invert of an aqueduct, and the details given, if worked out in this way, would be very misleading. It was not mentioned whether any experiment had been made to ascertain the liability of other natural stone to be absorbed or eroded by friction of the water. If examples of this nature had been given, it might have been less difficult to decide whether there was anything abnormal in the action of running water on the samples of limestone tested. Another surprising result was brought out in the increase in weight of the cement mortar, as compared with the decrease in the limestone. With two such actions going on it was not surprising that the concrete was disrupted. The increase in weight of the cement block must be due to something brought to it by the water. But the block must also have been worn to a certain extent, however small, by the action of the water upon it for 3 months. The gain in weight of 5·47 per cent. for neat cement and of 3·57 per cent. for cement mortar must therefore represent the difference between the growth and the erosion. Probably if these had been experimented upon in still water, the growth would have proved to be larger. Another important point was suggested by the unequal expansion of the neat cement and the cement mortar. The difference was represented as 1·9 per cent. per annum. This might be a cause of cracking between the various coatings if, as was stated at p. 170, the plasterers took the work in hand and trimmed the mortar face and finally, the mortar face was brushed over with a coat of neat cement. Too often in concrete work neat cement was used to finish off a slightly indented face. It was never successful in making a perfectly finished work, and the reason, no doubt, was unequal expansion of the various strengths of mortar, which was shown by the tests given in the Paper. With regard to the method of plastering the wall, would not the mortar have been more quickly handled, and would it not have made certain of a more homogeneous mass, to have erected all the side boarding within one or at the most two planks from the top at once, and then have poured the mortar in fairly uniformly along the whole length? When this process was used, a flat iron sword about 2 inches broad and $\frac{1}{8}$ inch thick was worked along the mortar so as to mix it thoroughly, cause all the air-bubbles to rise to the surface, and leave a perfectly smooth face. If this was carefully done, the mortar could be used of a good deal stiffer composition, because it became more liquid by working; no tapping of the planks, and no touching up on the face by plasterers was required. It had the further advantage that the planks did not require to be separated and built up again at each setting of the framing. Mr. Clark.

Mr. Duff. Mr. M. B. DUFF congratulated Mr. Tait upon the successful completion and sound construction of so large and important an undertaking as the Talla waterworks, but there were some parts of the work which he thought might have been carried out quite as efficiently and at less cost. Under the scheme as originally designed, it had been intended that the outlet-works should take the form of a culvert constructed in open cut in the solid rock and in a direct line through the embankment on the east side of the Talla Water. When the drawings were practically completed on these lines Mr. Duff learned with great regret, from the late Mr. James Wilson, M. Inst. C.E., on whose staff he then held a responsible position, that, upon the recommendation of the Consulting Engineer, the design of the outlet-works was to be altered, and a tunnel was to be constructed running into the hillside and round the end of the puddle-trench. This alteration was referred to on p. 113, and the difficulties resulting from it were detailed in the description of the "Outlet Works" on p. 116. Mr. Duff was of opinion that in such a solid formation as existed at Talla the best construction of outlet-works could be made in open cut, where the culvert works could be built upon the solid, carefully protected with clay puddle and refilled with selected material, and always open to inspection. He thought that the experience gained at Talla bore him out in this, for the Author showed that there was evidence that, through blasting operations, the rock might be shattered and broken for a distance of 5 or 6 feet outside the extrados of the tunnel, except at the points where the tunnel was afterwards opened out. For, although extra expense had been incurred in doing the work by tunnelling, openings had been made afterwards at both the inner and central shafts, whereby the open-cut system was reverted to in order to ensure sound work. Fig. 2, Plate 3, showed how the puddle-trench was eventually carried up to and around the central shaft and filled with concrete. Had the original intention been adhered to, many thousand pounds might have been saved without any sacrifice of efficiency, but rather the reverse. He quite recognized the fact that there might be places where it was not expedient to construct outlet-works in open cut

Mr. Duff. across the line of an embankment and its puddle-trench, but the site in question was not one of them. With regard to the waste-weir works, he was surprised to find that a two-arched bridge had been thrown across the channel, as shown in Fig. 2, Plate 3. When the work was designed, a special point was made by the chief advisers that care should be taken to guard against the channel being gorged by ice coming over the weir; and accordingly the channel had been deepened more than at first intended. A one-span steel girder-bridge was then intended, and surely this should have been adhered to, instead of introducing a pier right in the centre of the channel, thereby reducing its effective breadth and offering a serious obstruction to the free passage of ice. The extra upon Mr. Best's contract for the reservoir would appear to have been £46,000, or fully 30 per cent. on his contract-price. This was doubtless due largely to the difficulties met with in the construction of the outlet-tunnel, over and above its extra first cost over that of a cut-and-cover culvert. The suggestion, to which the Author referred, that pipes should have been adopted in place of the first seven tunnels most probably emanated from the lay mind. Besides the incontrovertible reasons given by the Author against this plan, it might be pointed out that, after all, it would only have amounted to the elimination of these tunnels at the expense of introducing a long tunnel between the ninth and fourteenth miles from the reservoir. At the latter point, as the work had been constructed, it was just possible to arrange for the aqueduct being in open cut by following the low ground between the rising hills on either side; and the introduction of 33-inch pipes involving greater loss of head would have at once converted this long length into very difficult tunnel-work, owing to the bad nature of the ground, described in the Paper under the heading "Cut and Cover Work." An important point was raised by the diagram (*Fig. 3*, p. 109) comparing the actual discharge with the calculated quantity of water resulting from the recorded average rainfall from the Talla drainage-area of 6,180 acres. As indicated by the Author, the loss due to evaporation for the months May to September, 1905, appeared to be smaller than had been allowed for by the rain-gauge arbitrators. In view of the Tables of evaporation at Glencorse it would appear that during these months fully 75 per cent. of the total annual evaporation took place. This meant that 11¼ inches should have been lost at Talla, that was, 75 per cent. of 15 inches. The loss at the end of the 5 months appeared to have been about 750 million gallons, representing 5½ inches loss of rainfall, taking the Author's figure of 140 million gallons of yield per inch of rainfall. The loss would therefore seem to have been only half what

Mr. Duff. was allowed for, notwithstanding the fact that the rainfall of 1905 (54·76 inches) came very near the average available (53 inches) in the driest three consecutive years. The drainage-area of the Talla was so steep and of such a hard formation that the loss by evaporation would not be expected to be as heavy as in ordinary areas. But great caution was required in coming to any conclusion upon so short a series of observations, and it might be that the discrepancy was due not altogether to a smaller loss by evaporation, but also to the average of the rain-gauge records not being the true average rainfall over the whole area.

Mr. Duncanson. Mr. THOMAS DUNCANSON remarked that although the absence of clay and suitable local stone must have added considerably to the cost of the reservoir, the cost per million gallons worked out favourably. No doubt the question of a masonry dam versus an earthen embankment had been duly considered, and it would be interesting to hear the Author's views as to the effect on the cost had a masonry dam been chosen. The decision to line the whole of the tunnels in the first instance appeared to have been a prudent one. Where it was possible at almost any time to obtain access to a tunnel for the purpose of executing work, some risk might be run; but where, after the work was once in use, it was practically impossible to put in lining which had been omitted, it seemed only prudent, if there was any probability that lining would be required, to make ample provision in the first instance. In view of the consumption in Edinburgh being about 40 gallons per head per diem, it would be interesting to know what the night rate of consumption was in the residential districts, and also what it was including trade and sanitary supplies.

With regard to Mr. Hill's Paper, Mr. Duncanson was thoroughly in agreement with the Author as to the importance of keeping complete records of the discharge from drainage-areas, and also records as to the manner in which water was disposed of in the districts of supply. Statistics of this character, although carefully kept in some waterworks, were no doubt neglected in many, especially smaller ones. The question of waterworks-statistics was, however, one of considerable complexity. Even on the apparently simple question of the true average rainfall on a district, as deduced from the records of a number of rain-gauges scattered over it, it was very easy for two equally competent authorities to differ by an appreciable amount. In the determination of the discharge from a district, great care was required if the results obtained were to be reliable. The selection of suitable gauges and proper formulas was of course necessary; and great watchfulness was also required, to make

Mr. Duncanson. certain that all the conditions for rendering the records of the gauges continuously reliable were properly complied with. From a practical point of view the most important question to be determined was the quantity which could be obtained from any gathering-ground under existing conditions, and for this purpose it was certainly desirable that conservative estimates should be adopted. The consequences of an over-estimate of the resources of a supply were so serious that it was surprising in how many cases it had been found that, in the hour of trial, the available supply had been too liberally estimated. Mr. Tait gave (p. 103) three different figures as the available supply from the old Edinburgh works; but it was obvious that, for purposes of calculation, the figure (*a*) could not be considered, and even (*b*) could only be considered with a reservation that, under some special circumstances, additional provision would be required. It was therefore desirable that, after carefully estimating the available supply, something should be kept in hand to meet the special conditions which only arose at times of great drought. Fortunately, in the more thickly populated districts, it usually happened that some adjoining district had surplus water which it was able to dispose of to less fortunate neighbours at such times, and in this way the consequences of over-estimating resources, or of not providing early enough for an ascertained want, had been prevented; but if reliance was to be placed on assistance of this kind, satisfactory arrangements should be made in good time.

r. J. W. Hill. Mr. JOHN W. HILL, of Cincinnati, observed that there were two or three points raised in Mr. Tait's excellent Paper which were of peculiar interest to one at a distance from the site of the work; first, the *per-capita* consumption of water in the Edinburgh district; secondly, the use of land above high water in the reservoir for grazing; thirdly, the reletting of the contract for the reservoir. Converting the unit of measure of consumption for all purposes to United States gallons, the consumption for 1870–71 was 28 gallons per head per diem, and for 1904–5 43·8 gallons, showing an increase in the consumption of 56·4 per cent., partly due to the increased consumption for domestic purposes, and partly to the largely increased use of water for commercial and sanitary purposes. While the percentage increase in consumption was large, the actual present consumption was very low when compared with almost any American city, as was shown by the Table on p. 239. Only in small cities, where the public water was not generally used for domestic purposes, would the consumption be found to be so low as 50 gallons per day. The low consumption in European cities was

Mr. J. W. Hill.

City.	Population, 1900.	United States Gallons per Head per Diem.
New York	2,049,000	120
Chicago	1,698,600	190
Philadelphia	1,254,000	229
Brooklyn	1,110,000	86
Boston	560,900	143
Cleveland	420,000	159
St. Louis	400,000	159
San Francisco	342,800	73
Cincinnati	325,000	325
Pittsburg	321,616	250
Detroit	306,055	146
Milwaukee	300,000	80
New Orleans	287,104	48
Minneapolis	202,718	93
Providence	187,300	54

ascribed to various causes, of which that most frequently mentioned was the necessity of conserving the natural sources of supply. While this cause would meet the conditions in cities like Edinburgh, which were compelled to secure their water-supplies by impounding-reservoirs, or cities like Dresden which depended upon driven wells, or Paris, which was compelled to draw from many sources to eke out its daily water-supply, it would not apply to cities like Hamburg and Altona, which had the whole River Elbe at command, or cities like Rotterdam on the Maas, or Glasgow, which drew from a lake of inexhaustible volume, and many other European cities which had sources of supply largely in excess of any present daily draught on them. According to the best sources of information, the consumption of water in Rome, in the days of Nero, with a population said by Gibbon to number 1,000,000, was more than 200 gallons per head per diem, a consumption which put to shame some of the wasteful American cities. Some other cause than limited sources of supply and costly works for collecting and conveying water must be at the bottom of the smaller consumption of water in European cities when compared with cities in America. If, in attempting to assign a cause for the low European consumption, Mr. Hill should fall into error, he hoped that correction would be forthcoming from his professional brethren abroad. The purchasing power of the dollar was greater

Mr. J. W. Hill. in Europe than in America, and a given water-rate would fall heavier on the Scotch consumer, for example, than it would on one in New York or Boston. Taking the Edinburgh rate at 10 cents U.S. currency for 1,000 U.S. gallons, this would be equivalent to 15 or 20 cents per 1,000 U.S. gallons in America, a rate which the water-consumer in large cities would not tolerate, and which, if any city offered to charge it for water in bulk, or by meter, or its equivalent, would bring about a wholesale condemnation of the city officials, and their removal from office at the next popular election. If the charge were assessed by a water-company in a city of 100,000 or more population the rates would not be paid, and the citizens would go to court with a charge of extortion against the company. Water was and must be sold at low rates for public supply in American cities, and this might be one reason for their large consumption. The unnecessary waste due to leaking pipe-joints, carelessness in the use of spigots, leaking fixtures, and excessive use of water for any of the domestic purposes, might account for the larger consumption of water in American cities; but tests of the *per-capita* consumption of water did not always bear out this theory. Many tests of isolated domestic supplies where the water had been metered, used through fixtures in good condition, and carefully handled, showed a purely domestic consumption per head per diem no greater than in many cities of Europe. A well-recognized cause of the increased consumption of water in American cities was the modern "sky-scraper," with lavatories in every room, toilet-rooms on every floor, and lavish facilities at every hand for the use of water by the tenants and in the operation and maintenance of the building itself. It could probably be shown, with reference only to the people occupying the tall modern office-buildings, that the *per-capita* consumption was quite doubled. The leasing, or even permitting the use, of the land above high water in the Talla reservoir for pasture, seemed to be a debatable, if not a hazardous, experiment. There were some apparently well-authenticated epidemics, and some endemic typhoid fever, which had been charged to water polluted by the discharge from grazing-lands. One case in point was that of the Appenzell Valley in Switzerland, where the mountain water was said to have been polluted with the bacillus *coli communis*, from domestic animals, and endemic typhoid followed. Several cities in the Rocky Mountain region of the United States had had epidemics of typhoid fever traced to a water-supply open to contamination from the offal from large herds of cattle which grazed on the watershed above the gathering-reservoirs, and some eminent sanitarians and medical practitioners in America would look

Mr. J. W. Hill. askance at any use of the drainage-area lying around and above the impounding-reservoir for stock-raising purposes. The theory that the colon bacillus from the domestic animals could be the cause of typhoid fever must assume that this organism with proper environment became the typhoid bacillus: this theory had been put forth a few years ago as a possibility by England's most eminent professor of natural history, and while no effort had been made to work out the proposition, Professor Lankester's suggestion had made some other people think that after all this organism might be the progenitor of the typhoid organism. There was less difference between the tadpole and the frog, or between the caterpillar and the butterfly, than there was between the colon bacillus and the typhoid bacillus. Nature was replete with larva which developed into something wholly unsuggested by the original thing, and why might not the well-known difference between the two intestinal organisms be brought about by the changes in environment of the colon bacillus from domestic animals, when ingested by the human system through the medium of drinking-water? Colour had been given to this theory by typhoid epidemics apparently susceptible of no other explanation. Certain mountain sources of water-supply in the western part of the United States were open only to contamination from stock-raising on their drainage-grounds, and the users of such water were often the victims of typhoid fever, which was usually traced to the drinking-water. It was safe to say that the typhoid bacillus, as such, had never been found in a natural drinking-water, while the colon bacillus was often, and in some drinking-water sources always, found. Why, if water was the carrier of the typhoid bacillus, was it never found, and why was its ally and nearest congener so frequently found in water known or supposed to be the cause of typhoid outbreaks or endemics? It was sometimes said that the numbers of the typhoid organism in a polluted water were so small that it could not be expected to find them on the gelatine plates when incubated, but this did not fully explain the universal absence of the bacillus, notwithstanding long and diligent search for it. Speaking as one who had built and controlled many works of public water-supply, he would certainly object to and prevent, if possible, any occupation by man or animals of the drainage-area which constituted the source of water-supply, believing that the offal from either might be injurious to man when the water containing it was ingested. The reletting of the contract for the embankment of the reservoir opened up a wide field for discussion. If the original contractor at his price of £160,000 had a profitable contract, then the second contractor, at a price of

Mr. J. W. Hill. £150,000 for 66 per cent. of the work, had an unusually attractive piece of work; or if the last price was fair and yielded only a reasonable profit, then the man who took the original contract must have made a regrettable blunder in his estimate of the cost of the work. The letting of public contracts under laws which prohibited any display of sympathy by officials, for unexpected difficulties encountered in the work, was beset by many hazards to the honest contractor. To bid a safe price usually meant to bid a high price, and to bid a winning price often means disaster, both to the contractor and to the principal. An engineer was not supposed to view the difficulties of a piece of work from the contractor's standpoint, no matter how meritorious his complaint might be, but to insist upon the work being performed at the prices written in the tender, even when he knew that such prices did not compensate the contractor for his outlay of money and personal labour. A more painful position was scarcely conceivable than one wherein a fellow-man, through his mistaken judgment, inexperience, oversight of impending conditions, or the perverseness of Nature, was being driven to bankruptcy and ruin in the discharge of a contract obligation which, when entered into, he fondly hoped would bring him some gain for his labour and expenditure of capital. Mr. Tait was to be congratulated on the success of his work, and the admirable Paper descriptive of it, and Mr. Hill sincerely regretted the lack of time to discuss other equally interesting points in which the Paper abounded, particularly the details of tunnel-work, on which, had time been available, Mr. Hill would have liked to compare his notes with Mr. Tait's experience.

Mr. Howarth. Mr. FRANK HOWARTH remarked that the subject dealt with by Mr. Hill was very important, and most waterworks-engineers would agree that there was a need of systematic observation of the yield of drainage-areas, in order to furnish data which would enable works to be designed in the most economical manner. Probably many engineers in charge of areas already appropriated by the large towns possessed records of the rain falling on such areas during considerable periods; but it might be taken for granted that comparatively few were in possession of records of the daily flow off the ground. It was not sufficient to fix weirs on the streams flowing into a reservoir, and to take daily gaugings at a fixed time each morning, as the flow often varied very considerably during a period of 24 hours, due to rain. In some districts a perceptible variation occurred during this period even when no rainfall had been registered on the area, the flow sometimes being larger at night than in the day, presumably owing to the smaller evaporation by night than by day, and to dew. The measurement of flood-discharges would entail considerable expense, as large pools and long weirs were necessary; but in most instances the value of the data available would more than justify the cost. One important matter in connection with records of this character was the dry-weather flow, which varied largely according to the physical and geological character of the drainage-area. Particulars regarding the nature of the surface, whether peaty, marshy, agricultural land, or bare rock, would therefore be very valuable; also, whether the geological sub-strata were of a permeable or impermeable nature, fissured or otherwise. In some districts the dry-weather flow fell so low that it might almost be ignored in making calculations regarding storage-reservoirs, but in others, such as the Dartmoor granite areas, the case was very different. The portion of Dartmoor from which the water-supply of Plymouth was drawn might be cited as an instance. From 1892 to 1898, gaugings of the flow were taken by means of an ordinary automatic recorder, and for many years before 1892, by daily measurement of the depth of the flow over weirs. In 1898, when the Burrator reservoir was opened, the position of these weirs was submerged, but since that time periodic summer gaugings had been taken at a point some distance higher up the stream. The quantity flowing off the ground at these points has not on any single day worked out at less than 1 cubic foot per second per 1,000 acres. In order to continue these records the Corporation had completed, about 6 months ago, the erection of a recording-station at the point where the River Meavy now entered the Burrator reservoir. Walls had been built along the river-banks, a pool had been formed, and two weirs had been built, with gun-metal lips: one weir was 20 feet long, for ordinary flows, and the other 50 feet long, with its lip 1 foot higher than the lip of the 20-foot weir, the two together measuring floods. A Hutchison recorder registered continuously the depth of water passing over the weirs, also the amount in gallons per minute both over the smaller weir when acting alone, and over the two weirs combined when acting together. By means of a penstock and tumbling-bay the water could be turned through a by-channel for the purpose of cleaning out the pool. The instrument would measure floods equal to about 325 cubic feet per second per 1,000 acres. There were eleven rain-gauges fixed in suitable positions on the drainage-area—five read daily and six monthly—with the records of which it was intended to compare the discharge off the ground. Mr. Howarth.

Mr. ALEXANDER JERVIS observed that it might be inferred that a fairly secure bottom for the trench had been reached, at a moderate depth, except at the easterly end, where the shattered greywacke Mr. Jervis.

Mr. Jervis. rock had given trouble, rendering it imperatively necessary to form a connection by concrete with the centre shaft of the tunnel and the puddle trench. This of course had entailed a large amount of costly intricate work. There was also the waste-weir channel crossing on the top of all. It was gratifying to know that by the means taken the difficulty had been satisfactorily overcome, although at considerable outlay. When the late Mr. Wilson was Engineer to the Edinburgh and District Water Trust the question tunnel versus culvert outlet arose, and the tunnel was decided on. However, from his own experience, Mr. Jervis thought then that it was a mistake. The site of the bank was in every way suited to form the base for a large embankment, and it had several natural advantages. The contour of the valley and river offered a favourable opportunity for constructing a culvert outlet for flood-water, as well as for the discharge- and compensation-pipes. The culvert could have been carried along the east side of the river deep enough in the rock cutting to be protected from all extraneous movements, and with the outlet-shaft placed on the up-stream end. Experience had shown that culvert outlets, when properly constructed, had advantages in many respects; for one thing, the material and workmanship could be seen and inspected. One of the most substantial culvert outlets ever constructed was that at the Gladhouse reservoir of the Edinburgh waterworks. At the commencement a trench, upwards of 100 yards in length, was cut in the sandstone rock, deeper than the culvert, and sufficient for the whole work to be taken in hand. It had a stone invert, and consisted of six rings of brick arching, wholly surrounded by a thick backing of concrete. The maximum internal dimensions of the culvert were 9 feet by 8½ feet, and it was sufficient to discharge the flood-water from the drainage-area of 6,131 acres while the works were under construction.[1]

Mr. Maxwell. Mr. W. H. MAXWELL, of Tunbridge Wells, was in entire agreement with Mr. Hill as to the great public importance, as well from a national as from a local point of view, of keeping reliable records of the rainfall and surface yield of catchment-areas, in order that a greater wealth of data might be available upon which to base designs for impounding-reservoirs. He also strongly supported Mr. Hill's suggestion that every water-undertaking should do its share in carefully recording all possible facts relating to rainfall and yield, and that the engineer should endeavour to deduce accurate conclusions from the observations so made. But he desired more particularly to

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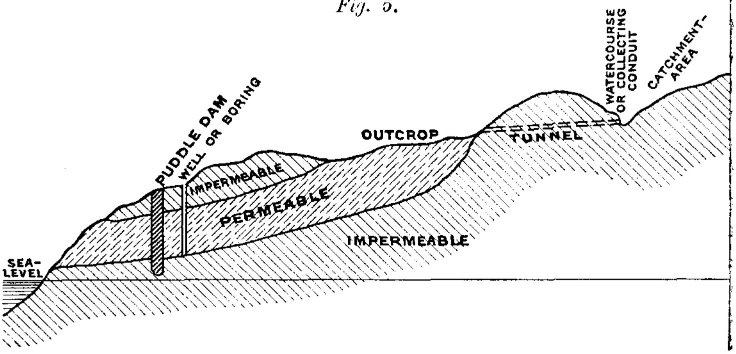
[1] A. Leslie, "The Edinburgh Waterworks," Minutes of Proceedings Inst. C.E., vol. lxxiv, p. 91.

Mr. Maxwell.

extend the application of the importance of these observations, to which Mr. Hill had ably drawn attention, to their bearing upon water-supply derived from underground sources. The true relationship between rainfall and the yield of subterranean water from any given catchment-area or basin was, in Mr. Maxwell's opinion, a matter of first importance in all districts such as the south-eastern part of England, where reliable surface supplies, so general in the north and west, were, as a rule, outside the range of practical politics. The same remark applied to many parts abroad, such as, for example, Algeria, Cape Colony, Queensland, the United States, and other countries where the respective governments had taken up the task of obtaining underground supplies as a question of national importance. It had been Mr. Maxwell's duty for a number of years past, as the engineer responsible for the Tunbridge Wells water-supply and that of an extended area comprised within a circle 6 miles in diameter, to observe very closely and to record the relation obtaining between the local rainfall, the water-levels, and the yield of the several wells which he had had occasion to put down and bring into use during recent years. The same applied to the yield of about sixteen springs scattered over a wide area, which also contributed to the total supply. The droughty period of 1900–1902, during which the rain-gauge at the central station of Tunbridge Wells waterworks recorded a rainfall as low as 20·06 inches per annum (1901), had impressed upon him the practical importance of studying the relation between rainfall and the possible yield of subterranean water-basins. He believed that, in this connection, valuable assistance was obtainable from the study of practical economic geology, and that this science should be pursued by the waterworks-engineer with a deliberation scarcely less serious than when prospecting for coal, iron, or other minerals. To this end he had collected the fullest available data of all wells and borings within many miles of his own operations, and, after marking their position upon a map of the neighbourhood, and plotting cross sections of the wells and intervening country, he had marked thereon the relative "rest" and "pumping" water-levels, depth of wells, geological details of strata passed through, and all other obtainable information of probable value. These data, with observations of the varying rainfall within the catchment-area, pumping-records, and the varying depths and "dip" of water-bearing strata at different sites, constituted a vast body of useful information on the yield of underground basins. In this work he had been much assisted by the excellent memoirs now being issued by the Geological Survey Office, on the underground water-supply of different counties: the usefulness of such records to

Mr. Maxwell. the waterworks-engineer would be greatly enhanced if in them could be embodied the local rainfall and pumping-data. Mr. Hill's point, that year by year the unappropriated stream and river-basins suitable for the supply of towns became fewer and more difficult to obtain by a municipality in search of a reliable supply, applied with perhaps even more force to subterranean water; and when the engineer was driven to seek a supply from this source, his difficulties in a more or less unknown subterranean area were increased in every way. Scanty as might be the records upon which to calculate the yield of surface catchment-areas, still fewer were the data available in regard to subterranean water. The basin lay, perhaps, hundreds of feet below the surface, and might be both fed and drawn upon in many unknown directions; and for these reasons the plea for systematic records upon which might be based safe conclusions as to the exact relation and mutual effect of rainfall, subterranean water-levels, and pumping, deserved to be strongly emphasized. In the case of surface catchment-areas, such as were referred to by Mr. Hill, the engineer invariably took steps to impound the water falling within a given watershed. In Mr. Maxwell's opinion, there were instances in which the same principle could be usefully applied to the conservation of underground supplies, in order to prevent the water from leaking away into river-beds and to the sea. A typical case might be illustrated by the accompanying diagram (*Fig. 5*), in which a puddle dam or wall was placed so as to intercept water, and thus give rise to an artificial head in the permeable strata, a well or boring being sunk near the upper side of the dam. The diagram was also intended to illustrate one way in which the natural yield of an underground source might be increased by conducting water by means of a tunnel or conduit from an extensive surface catchment-area of an impermeable

Fig. 5.



Mr. Maxwell.

character on to the porous outcrop of the water-bearing strata, thus largely augmenting its capacity as a subterranean source of supply. The surface waters so utilized would be purified by the natural filtration to which they were ordinarily subjected in the course of downward percolation. Mr. Maxwell had put this principle into practice during periods of considerable rainfall by discharging surplus spring-waters, the purity of which was undoubted, down a 400-foot steel-lined boring into a water-bearing strata from which large supplies were derived during dry seasons. All reservoirs being full, this surplus would otherwise have run to waste down the nearest watercourse. In estimating the yield from underground catchment-areas or basins, he considered the following to be the principal determining factors:—

(1) The area, slope, and physical character of the "outcrop" of the water-bearing strata, and the extent to which the rainfall from adjoining impervious areas might be conducted to such permeable surfaces.

(2) The average yearly rainfall over the surface catchment-area, and the percentage of percolation.

(3) The extent of the underground contributing area or basin; the degree of permeability of the water-bearing strata; and the percentage of the total percolation again recoverable by means of pumping.

(4) The amount of leakage or escape of water from the subterranean store, such as through natural outlets to river-beds and to the sea.

He also held the view that, having regard to the large and increasing population dependent upon underground supplies, the question of the conservation and artificial increase of the yield of subterranean water-bearing areas was destined in many parts of England and abroad to form an important part in the water-engineering works of the future.

Mr. Murray.

Mr. JAMES MURRAY, of Edinburgh, observed that in Mr. Tait's Paper, which was naturally confined to engineering matters, there was no reference to the problem of the relation of biology to water-supplies. Yet, in providing a water-supply for a great city like Edinburgh that was a very important matter, and one which had been seriously considered in selecting a site for the new reservoir. He therefore desired to discuss briefly the conditions governing the increase of animal and vegetable life in lakes and reservoirs, and what might be expected from the special conditions affecting the Talla waterworks. It had to be admitted that very little was known as to the actual means by which life found its way into

Mr. Murray. reservoirs, the time required to stock them, or the causes which produced undue increase. One thing was indubitable, namely, that a long-continued high temperature in summer would foster the growth of organisms. Trouble from this source had been experienced only in small or at any rate shallow reservoirs, and it followed that it was important to make reservoirs as large and as deep as possible. Contamination of the water in a moderate degree with sewage was favourable to the increase of life, and for this, as well as for more important reasons, it was desirable to have as pure a supply as possible. The situation of the Talla reservoir, at an elevation of nearly 1,000 feet above the sea, its drainage-area of mountainous and all but uninhabited country, its surface area of 300 acres and total capacity of 2,800 million gallons, would all lead to the expectation of a loch filled with pure water, never of excessively high temperature, in which an undue increase of organisms would not be likely to occur. The Talla reservoir presented an unequalled opportunity for studying the rate of increase in the animal life. Its upland situation and the distance of the nearest lochs, with hill-ranges intervening, would have led to the anticipation that it would have been slowly stocked, and that the process might have occupied some years. Sir John Murray had permitted this opportunity to be taken advantage of, and the water had been periodically examined during the first year after the opening of the works. The result had been rather surprising. In the course of a few months the reservoir had become as fully stocked as a permanent loch. There was nothing disquieting in this. It was unlikely that the increase would go on till the life exceeded that in an average large lake. The proximity of St. Mary's Loch, the nearest large loch, invited comparison with Talla. It appeared from Mr. Tait's Paper that engineering difficulties had chiefly led to the rejection of St. Mary's Loch as a reservoir for Edinburgh. Examination in midwinter had shown the life in that loch to be unusually abundant, sufficiently so to render the water turbid, and far in excess of what was found in Talla in summer. Mr. Murray attributed this to the pollution of the water, which was collected chiefly in two populous glens. The winter temperature of the Talla reservoir was not yet known. The temperature during the first winter (1905–6) could not be regarded as a normal winter temperature, as the loch had not then experienced a summer's heat. Further observations were needed to determine the annual range of temperature, and the time which it would take before the life in the loch attained to the kind of equilibrium which was observable in permanent lakes, and which was disturbed only by exceptional conditions.

Mr. Paterson.

Mr. **Malcolm Paterson** observed that, although it was not actually stated by Mr. Barnett, he inferred that the concrete lining of the Thirlmere aqueduct was made with Portland cement, but no mention was made of the sand used. It would be useful if the proportions and character of the ingredients were given. Mr. Paterson had not been aware of the existence of an important aqueduct made with, and at the same time in, the carboniferous limestone. Could the Author state what precedent, if any, had guided the engineers to the use of this economical expedient? The fissured and honeycombed character of this formation was well known: it was impossible to tell at any given point in the rock whether the apparently solid surface was not a thin shell hiding a cavity, which might be small or large, but was almost certain to be a natural water-duct, the more or less continuous flow of water causing that solution and abstraction of the lime which formed the cavity. Knowledge of this fact dictated extreme caution in dealing with a limestone floor, which in some measure had been observed in the case of the Hutton Roof tunnel, Section No. 2, where "all the fissures met with had been carefully filled during construction." Special mention being made of filling in this section, was it to be taken that the cut-and-cover Section No. 1 had not been so treated? If so, this might largely account for the comparative incidence of leakage in the two sections, namely 2,407 gallons per lineal yard per 24 hours in No. 1, and 191 gallons in No. 2, although in the latter case the tunnel-section was entirely walled with the limestone rock. Touching the remedial measures, the thick cement lining would undoubtedly effect its primary purpose of protecting the wetted perimeter of the aqueduct from undue waste. Whether it was safe to leave in the limestone concrete found in many places below the water-line "quite rough and honeycombed" after 10 years' use, was another question, the answer to which depended largely upon the extent to which surface water found its way into the rock contiguous to the aqueduct, and thence into the concrete itself. If outside water did so penetrate, such penetration would certainly increase, and difficulty would arise. At the same time, the remedy adopted might serve its purpose for a long period. A 12-inch floor of cement concrete on a foundation of this limestone, with the latter thoroughly cement-grouted under a head, would have brought peace of mind to all concerned at no excessive cost for so moderate a length, though entailing much more interference with supply. As a remarkable instance of a fissured formation below a reservoir, he might cite the case of the Red Hill service-reservoir of the Castleford Urban District Council in the West Riding, which he inspected on behalf of the Council in 1897, reporting that the

Mr. Paterson. fissure in the magnesian limestone below the reservoir extended on each side beyond its full diameter of 75 feet, was 27 feet deep throughout, and had an average width of 3 to 7 feet. This tank had been constructed by Mr. Filliter in 1870, and the 9-inch concrete bottom must have bridged this fissure for many years before it finally collapsed about 25 years later. It should be stated, however, that old workings for moulder's sand at a depth of 30 feet and upwards, had previously undermined the site, causing serious settlement; and no doubt continuous leakage over a number of years had enlarged the original fissure.

Mr. Smith. Mr. Cecil B. Smith remarked that, in Great Britain, density of population, cheap coal, and the comparative insignificance of waterfalls or rapids as potential sources of power, conspired to hold the attention of the engineer, in his study of the discharge of water from catchment-areas, almost entirely to the question of its effect on the total yearly yield for drinking and for other domestic or manufacturing uses. In Canada, however, conditions were very different, and while certain districts were beginning to be affected by the contamination of the water-supply, the question was not yet vital, and excited only local interest. On the other hand, in the central and more populous provinces of Ontario and Quebec there was no coal, and Nova Scotia coal was little more than a regulator to the selling-price of coal obtained from Pennsylvania and West Virginia. Fortunately, however, both provinces were more than ordinarily blessed with water-power, and their future manufacturing interests were assured by the advance in the science of water-power development, as applied to the generation of electrical energy, and the distribution of this energy over extensive areas, already accomplished to a considerable degree in several large manufacturing centres. The Provincial Government of Ontario had still vested in its control for the Crown, or under lease to companies or municipalities, a large number of these water-powers; but full information in respect to their value, extent, location, and availability for development along economical lines, had been felt to be lacking, as also accurate knowledge of the industrial demand for such power, or the amount already in use. Consequently, in July, 1905, a provincial hydro-electric commission was appointed, with wide powers, to examine fully into these questions and others of an allied nature affecting the industrial progress of the province; and Mr. Smith was appointed Chief Engineer to this commission. When it was realized that the province was 1,300 miles from east to west, and 800 miles from north to south, with its population of 2,500,000 confined to the southern portion, some idea might be formed of the magnitude of that portion

Mr. Smith.

of the inquiry relating to the study of the main hydraulic features. It had soon become evident that either a large expenditure was necessary, or else the treatment of the question must be general in character, with certain types more fully studied to serve as a basis for generalizations; and this latter method had been chosen as suited to the justifiable expenditure. For the purpose of examination the province had been divided into hydraulic districts, namely, the main drainage-areas tributary to the Ottawa River, the St. Lawrence River, Lake Erie, Lake Huron, Lake Superior, the Winnipeg River, and the Hudson Sea, and field-engineers had been sent out to examine each river in detail, with general instructions to make a walking or canoe traverse, determining distances by time or maps, and elevations by barometer and, locally, by hand-level. In this manner, a rough profile of each river and its tributaries had been obtained; while at each important fall or rapid more careful levels and measurements had been taken, and where any hydraulic developments already existed, careful statements had been prepared, showing the extent and condition of the same. Evidently, for power-purposes, given the head under which a development might be economically made, the main feature of importance was the minimum flow under natural or artificial conditions, and, locally, the pondage creatable to enable the variation in daily load to be provided for. Minimum flow could be determined only by a continuous series of observations, extending over many years: evidently this was not immediately available, and, for the present, the minimum flow had to be arrived at by deduction from a limited number of observations, and a study of rainfall-records extending over a long period of years. Accordingly, the gauging of each river in general had been confined to one determination, and certain rivers, namely, the Severn, Trent, Nipigon, Kaministiqua, and Rainy rivers, had been selected as types, and gauges had been erected and read daily for a year. Several measurements had also been made with mechanical electrical meters, or by pole floats, depending on the time of year and local conditions; and in these ways a fairly accurate knowledge had been obtained of the variations of flow, from day to day, and estimates had been made of the minimum flow from each catchment-area, based on the area, its proportion of forest and cleared land, and the extent to which lakes, swamps, and artificial reservoirs appeared to regulate its flow. Other things being equal, a small area would provide a proportionally smaller minimum discharge per square mile than a larger one; but in Ontario the much more vital feature was the existence of lakes and forests in the upper parts of the areas; and fortunately, if the south-western peninsula were excepted, which had been nearly denuded of forest, the rivers were singularly well

Mr. Smith. conditioned for the regulation of flow. Roughly speaking, the minimum flow per square mile of catchment-area varied from one-tenth to five-tenths of a cubic foot per second, but in most cases it was between two-tenths and three-tenths where lakes were somewhat plentiful, rising as high as five-tenths in the case of the Trent River which had had artificial pondage well developed by the construction of the Trent Canal. Giving reasonable values to minimum flow, it might be estimated that at points capable of economical development, and counting on only one-half of the power of the St. Mary, Niagara, St. Lawrence, and Ottawa rivers as available to the province, at least 3,500,000 HP., taking 75 per cent. as the efficiency of the machinery, was available to the present populated portions of the province; and that along the tributaries of the north shore of Lakes Huron, Lake Superior, and the Hudson Sea, and along the Winnipeg River and its tributaries in Ontario, at points still remote from population, there was at least 2,000,000 HP. additional which had not yet been more than partially determined upon, and for which there were yet no users, but which would in another generation or two be also in demand. A considerable portion of the 3,500,000 HP. was already developed, or in course of development; and when a full realization of the value of these water-powers became more widespread, they would be rapidly harnessed for industrial uses, and the regulation of flow would be more carefully studied and carried out by the proper authorities.

Mr. Thorp. Mr. R. F. Thorp suggested that it would be interesting and instructive if Mr. Tait could provide even a rough contoured plan of the catchment-area showing the position of the several rain-gauges. The plan should not only show the actual catchment-area, but should also include the surrounding country, more especially on the side from which the prevailing moisture-bearing winds blew. The configuration of the country surrounding a rain-gauge had a marked effect on the rainfall registered by the gauge, much more effect, indeed, than the actual elevation of the gauge above sea-level. During the last 9 years Mr. Thorp had been able to study the rainfall in the Western Ghauts of South India under rather favourable conditions. In the district referred to, there were upwards of thirty gauges within an area of 200 square miles, and many of these were situated within 1 mile or 1½ mile of each other. A daily register was kept of all the gauges. The extreme rainfalls registered ranged from 80 inches to 380 inches in a year. In some instances the difference between the readings of two gauges less than 2 miles apart amounted to as much as 100 per cent., even when the gauges were placed in what appeared to be equally

Mr. Thorp.

suitable positions. Under similar conditions the daily rainfall varied as much as 150 per cent. in gauges only ½ mile apart. He had found that, in order to obtain a maximum reading, the gauge should be placed a short distance on the leeward side of the crest of a main ridge—that was to say, leeward in respect of the prevailing moisture-bearing winds. The minimum rainfall was frequently registered near the bottom of the leeward slope of the same ridge. The mean fall on any particular area was very difficult to estimate, and the relative value of any reading could not be judged without some reference to the force and direction of the winds and to the general configuration of the country surrounding the catchment-area. The scarcity of data regarding the rainfall in outlying districts was one of the chief difficulties with which hydraulic engineers in India had to contend. The yield of a particular area could be estimated only from personal knowledge of the locality. In India it was taken to range from 6 per cent. to 80 per cent. of the total rainfall; 5 per cent. was sometimes taken as a safe allowance for preliminary estimates. It would also be interesting to know what was the maximum flood-discharge allowed for in the design of the Talla waste-weirs.

Mr. Watson.

Mr. JAMES WATSON observed that the cost of the Talla reservoir worked out at £90 per million gallons stored. In England, especially in Yorkshire and Lancashire, the cost per million gallons stored often amounted to three times this sum, so that Edinburgh, in addition to having a well-designed and substantial reservoir-embankment which reflected much credit on the engineers and contractors, was to be congratulated on the reasonable cost of the work. The tables of rainfall, discharge, and evaporation were specially useful and interesting, and formed a valuable contribution to the small body of accurate information existing on these matters. The purchase price of £36,000 for 6,180 acres of drainage-area (£5 16*s.* 6*d.* per acre) applied to a country where that intangible excrescence to the Lands Clauses Consolidation Act known as "special adaptability" was not recognized in any award known to Mr. Watson. In England the claims set up under the head of "special adaptability" for land, good, bad, and indifferent (if it had to be acquired under statutory powers for waterworks), were such that land which would not command in the open market £10 to £30 per acre, instantly appreciated to ten or twenty times its agricultural value, if needed for waterworks, on the grounds of one or more of the ill-defined pleas of "special adaptability." Mr. Tait might have touched on another matter which was of great importance to waterworks-undertakers, and with which he was well acquainted, namely, the case of

Mr. Watson. Somerville against the Edinburgh Water Trust, where it was contended that compensation-water must be of some standard of purity. In this particular case the standard was to be arrived at by means of what one gentleman engaged in the Court of first instance called the "danger-limit," which "limit" was to be indicated by a red mark on the gauge-board. When the surface of the water in the reservoir fell to the red mark on the gauge, the city supply should be shut off and only compensation-water should be sent out. The House of Lords had decided against Messrs. Somerville and the danger-signal; but had the decision been against the Trust, every waterworks-undertaking in the three kingdoms would have been face to face with financially impossible schemes of filtration, or, alternatively, claims for damage on the ground of compensation-water not being of some empirical and inapplicable standard of purity and colour. The application of the novel suggestion of the so-called danger-signal would not once in a thousand times do what was claimed for it. Water delivered from impounding-reservoirs in times of flood was often sent out in a state similar to that in which Nature had sent it in, but as a rule it was given out during a large part of each year better in colour and quality than it had been in the days when the stream was unregulated.

Mr. Barnett's Paper clearly showed the danger of using the ordinary limestones of the Yoredale series for concrete in the thin walls of tunnels or cut-and-cover work, where subjected to the action of soft water. In the construction during the years 1893–98 of the Nidd aqueduct through the Yoredale rocks, 33 miles in length, on which Mr. Barnett had been engaged, Mr. Watson had disallowed the use of limestone in the concrete lining of the walls of the tunnels and in the concrete lining of the cut-and-cover works; and in some miles of large concrete by-pass channels which he was now constructing at the Angram reservoir-works, where limestone abounded, he was following the same course.

The subject of Mr. Hill's Paper was a highly important one to the waterworks-engineer, and the obvious advantages to be derived from a knowledge of the yield of upland drainage-areas were carefully set out by the Author, as were the practical difficulties involved in securing even a reasonably accurate determination thereof. Twenty-five years ago Mr. Watson made many hundred measurements on the 300-foot waste-weir of a large reservoir into which flowed the whole yield of a drainage-area 18,000 acres in extent. He also made an accurate model of the weir, its apron, and crest, in order to ascertain, at various depths on the sill, the coefficient of discharge. While the 8 million gallons per day of compensation-water and the

10 million gallons per day sent to the town had been ascertained with accuracy, the continual rise and fall of the waste-weir, especially in times of flood, could be only roughly measured. The record of depths had been made by the caretaker and his assistants—always by day, and frequently by night; yet the want of a clock recording-gauge had left the deductions uncertain, and the calculated results open to doubt. Whenever proper works and appliances were erected to measure satisfactorily the yield of catchment-areas, a vast stride would be made in knowledge as to the proper application of rainfall-measurements and their bearing on water-supply. Mr. Watson.

Mr. Wm. Watts remarked that his observations, extending over 40 years, bore out Mr. Hill's statement with regard to the want of more reliable information as to the yield of moorland drainage-areas appropriated for waterworks. Mr. Watts began to measure the rainfall in the Swineshaw valley, near Staleybridge, in 1866. He had been continuously recording the daily fall in a number of other valleys since that date, and had had many opportunities of witnessing the effect of flood-discharges compared with the rate of flow off the land in normal weather. A maximum flood never lasted very long. The curves illustrating the rise and fall over the gauge-weir approximated very closely in time; and this phenomenon showed the importance of fixing stream-gauges to work automatically. The rate of flow depended on the physical features of the drainage-area, and on the distance of the water-parting from the point where the stream-gauge was fixed. In small moorland rivers it was not unusual to find the flow reduced during the warmer hours of the day below the night flow, owing to evaporation and absorption by vegetation. He entirely agreed with the Author's suggestion that stream-gauges should be permanently fixed to measure the river-flow from all important watersheds in the country, and that such gauges should be in the hands of an independent body, the information being available to those interested persons who sought it. The wealth or poverty of a watershed could not be determined without stream-gauges, as a few scattered rain-gauges were insufficient to render the records trustworthy and reliable. The position of many rain-gauges, as at present arranged, was open to objection. They were sometimes placed in situations where the heaviest rainfall would occur, and the records thus obtained formed a misleading basis for the estimation of the yield of the whole drainage-area. Stream-gauges would show the true yield. In his opinion few drainage-areas in the country were utilized to the full extent of their yield of water, in consequence of the reservoirs not having sufficient capacity to store flood-waters. All corporate bodies should Mr. Watts.

Mr. Watts. be compelled to utilize fully their resources before other areas were granted to them. He considered that in order to cover a district efficiently rain-gauges should be placed in zones, say in elevations of 200 feet, following the contour of the watershed. This plan would, he felt sure, indicate a truer average rainfall figure than that of placing a few gauges in the most exposed situations. In order to deal with the rainfall-areas efficiently, they should be placed in the hands of men who understood the hydrographic and meteorological features of the country, and who were not influenced by local interests.

Mr. Tait. Mr. TAIT, in reply, remarked that he was pleased to observe that criticisms had come from across the Atlantic, for, as one of the Institution party which visited Canada and the United States in 1904, he had thoroughly appreciated the excellent arrangements which the engineers there had made for the reception of the British engineers, and the many facilities afforded them for the freest possible inspection of works. Canadian and American engineers were perhaps more fortunate than their British brethren, in the sense of having really big drainage-areas to deal with. It did not appear, however, that there was much room for criticism in regard to the actual carrying out of already completed schemes for water-supply and power purposes. It was very satisfactory to note the trouble the authorities had taken in regard to making surveys of the remaining sources of power, though it appeared that a much smaller sum than usual had lately been voted for the continuance of stream-gauging and other hydrographic investigations of the United States Geological Survey.[1] In visiting Niagara under Mr. Smith's guidance Mr. Tait could not help feeling that the large new power-works there then being carried vigorously towards completion were only an earnest of many more large power-schemes in other places. Mr. Smith had contributed some useful information in regard to a matter which ought to be very carefully recorded and studied, namely, dry-weather flow. Mr. John W. Hill had also made a very important contribution to the discussion, containing some useful figures. Notwithstanding the explanations given to the visiting members of the Institution in America, it seemed difficult to justify the enormous daily consumption of water per head of population. Mr. Tait preferred that undue waste should be checked and ordinary supplies kept within reasonable limits. It seemed on the whole fortunate for the American authorities that they did not come under the obligations of the Water Works Clauses

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[1] See *post* p. 464.—SEC. INST. C.E.

Mr. Tait.

Acts to deliver water to the top stories of buildings. Mr. Tait understood that persons occupying "sky-scrapers" had themselves to pump water delivered to them at or near the basement. Mr. Hill's suggestion about not leasing the drainage-area for pasture was a serious one from many points of view, and Mr. Tait had at once taken steps to draw the Water Trustees' attention thereto. It must, however, be remembered that if Mr. Hill's view was correct, an immense area in the British Isles should at once cease to be used for any agricultural or farming purpose whatever. One advantage which might be gained by this would be that the great question of afforestation would be sooner dealt with. In dealing with the question of re-letting the reservoir contract, account must be taken of the great rise in prices of labour and materials, in both Scotland and England, between 1897 and 1899. It was now the general opinion that Messrs. Young's offer for the reservoir should not have been accepted. While Messrs. Duff and Jervis, from their personal knowledge, had relieved the late engineer from responsibility for the extra cost involved in making a tunnel in place of a culvert, as originally intended, Mr. Tait did not think that this finally disposed of the question whether or not culverts were preferable to tunnels clear of the embankment.[1] Only a year or two ago Mr. Tait had experienced considerable trouble with slips in the neighbourhood of a lately-constructed reservoir which ended in the carrying away of a large portion of the outlet-works. Temporary outlet-works were installed, but it became absolutely necessary to drive a tunnel through solid rock into the reservoir, in order that water stored there might be properly under control. In view, however, of the experience with the Talla tunnel it was manifest that there must either be no blasting at certain important places, or at any rate a great deal of rock must be removed by plug and feather after that blasting had been performed, in order to make certain that no shattered rock with open fissures had been left. Mr. Tait understood that pressure had been brought to bear upon the Trust that the material in the puddle-trench should be as homogeneous as possible, but reference to Fig. 2, Plate 3, showed how much the actual differed from the ideal. With a masonry dam it was obviously easier to alter the position of an intended culvert than with an earthwork dam. Where two independent culverts were provided, the putting in of plugs was a much simpler matter. The question of the reasonable limit of drainage-area which it was desirable to attempt to control with only one culvert did not appear to have been raised in the discussion. It was

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[1] For a discussion on this subject see Minutes of Proceedings Inst. C.E., vol. lix, p. 50.

Mr. Tait. important that what happened at the Gladhouse reservoir in 1891 and 1892 should be recorded. Probably as the result of the Talla Paper, including Mr. Barr's observations, there might be an even freer use of gun-metal in the future where very soft water was concerned. Mr. Tait would have been glad if Mr. Bryan, in forwarding his diagram (*Fig. 4*, p. 232) had explained why the total flow from the gathering-ground in the year 1897 was so small in relation to the total rainfall in that year. In reply to Mr. Duncanson, Mr. Tait had looked into statistics of the consumption between midnight and 5 A.M. in residential parts of Edinburgh and District and had found that it varied between 170 and 500 gallons per hour per thousand of population. The great difference in level between different portions of the compulsory area to some extent accounted for the range. He agreed with Mr. Howarth that, with the use of proper recording instruments, the point to which he and Mr. Watts had drawn attention, namely, the flow from a particular drainage-area being larger at night than by day would be more easily observed. It was to be hoped that Mr. Howarth's rain and stream-gaugings would be continued and published, special regard being had to the point he had brought out about the minimum dry-weather flow. Mr. Tait had heard with great interest one of Mr. James Murray's papers on animal life in reservoirs, in which some particularly interesting observations were recorded in regard to reservoirs in the West of Scotland of which Mr. Tait had personal knowledge; and he rather regretted that, while an engineering description of recently-completed works should be read at an early date in the Institution, this did not allow sufficient time for the observations which Mr. Murray was carrying on. Possibly, however, on another occasion Mr. Murray might be able to communicate his further results to the Institution. It was unfortunate that Mr. Thorp had not been able to take part in the discussion at the Institution, as he would then have had an opportunity of seeing an excellent model of the drainage-area prepared by Mr. B. Hall Blyth, which, of course, was of much more use than any contoured plan. The Somerville case was, as Mr. Watson pointed out, an extremely important one for all British water-authorities. In this case *inter alia* Mr. Tait's administration of the Edinburgh and District water-supplies had been impugned, and several points other than those to which Mr. Watson referred had been raised. The Water Trustees, however, had been able to show that their undertaking had been authorized by Parliament, and that it had been administered in a reasonable manner. Quite apart from extraordinary weather conditions, a good deal had turned upon the

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question of regulation of the water in two reservoirs on the same stream. Mr. Tait had held, with the approval of many of his professional brethren and of a large majority of the ten judges who were engaged, that it was better, if at all possible, to let the lower of two such reservoirs fill and overflow before the upper had first filled. Commonplace as it might appear, the point had been argued at considerable length. It might be mentioned that ten members of the Institution, including two Past-Presidents and several members of Council, had been engaged in this important case.[1]

Mr. Barnett.

Mr. **Barnett**, in reply, observed that the entire renewal of the lining had been out of the question. The best that could be done under the circumstances was to remove all concrete which was at all doubtful in appearance, replace it with cement mortar free from limestone, and reface the water-surface of the culvert with like material. The portion of the aqueduct which was liable to the influence of the outside surface water was to a certain extent restricted to well-defined sections, and any trouble which might result from the action of this water on the concrete backing could be remedied by cutting out and renewal. In fixing the vent-pipes (*Figs. 12*, p. 175) care had been taken to have them inserted quite to the outside of the concrete lining, so as to render the pipes the easiest course for the water to follow, and thus prevent further damage to the concrete. The point referred to by Mr. Clark as to the wasting of the matrix was dealt with in Mr. Barnett's reply to the Discussion. The statement that the mortar surrounding the stones remained good, and stood up round each stone (p. 161) did not mean that the matrix had been absolutely unaffected. In the succeeding paragraph it was explained that the matrix was left in a rough and honeycombed condition. Very few leakages had been met with in the side walls where there was this thin skin of mortar to protect the larger pieces of limestone in the body of the concrete, and in almost all such cases the leakage had originated from the surface water forcing a passage through under pressure from outside. None of the loss in weight of the experimental blocks was due to mechanical friction against the concrete, and the current of water flowing over them had been comparatively insignificant. They had been placed on the floor of the large inlet-well, at such a distance from the vertical bell-mouth inlet-pipe as to prevent any possibility of movement. The waste as given in Table VI was not intended to indicate the rate at which the mass of the concrete lining was wasting away, otherwise there should have been very little of this concrete lining

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[1] A print of the House of Lords judgment is in the Institution Library.

Mr. Barnett. remaining at the present time. The experiments had been made only to show the rate at which the various kinds of limestone of which the concrete was made were affected by the soft water, and for this reason no other kind of stone than that actually used in the construction had been subjected to such tests. The gain in weight by the neat cement and the mortar blocks could hardly be accounted for by what Mr. Clark described as "growth." Both blocks had been carefully washed after being removed from the aqueduct, so as to remove all fine sediment deposited on them by the water. Neither did it seem possible to account for the gain in weight by the deposition of such floury matter in the fine pores of the cement and mortar blocks, as in that case the mortar block should have shown the larger rate of increase, owing to its being much more porous. No inference could be drawn regarding the relative expansion of the neat cement and the mortar blocks. These were quite different in shape, the cement being in the form of a short cylinder, and the mortar an oblong slab about ½ inch thick. As these were of exactly the same weight, the volumes would necessarily be different on account of the difference in the specific gravity. No special trouble should arise from unequal expansion, as the slight necessary trimming up of the new facework had been done with mortar of the same proportions as the new facing. The final wash of neat cement was in the form of a thin film, and had been applied only for the purpose of giving a more finished appearance to the surface of the wall. He did not consider that the method suggested by Mr. Clark of putting on the new facework would have given a better result than that adopted, which had proved quite satisfactory. The thorough working of the soft mortar by trowels as it was put in plank by plank would be more likely, in his opinion, to prevent the imprisonment of air-bubbles. If the fixed planks had been carried up more than half the height of the side walls, there would have been difficulty in properly working and withdrawing the long swords, on account of the flat segmental arch of the culvert. The removal, conveyance, and re-erection of the large slabs of framework would also have been a very awkward and difficult operation in such a constricted situation as the culvert at Hutton Roof. In reply to Mr. Paterson, the original concrete lining of the aqueduct had been made with Portland cement in the proportion of 1 measure of cement to 5 measures of broken stone. No specific proportion of stone and sand had been fixed, but it had been stipulated that the broken stone was to include the requisite proportion of clean, sandy material; also, the maximum size of the broken stone was not to

Mr. Barnett. exceed 1 inch, the greater part to consist of stone broken to a much smaller gauge. These proportions had given a very good close body of concrete. A sufficient proportion of siliceous sand from other parts of the district had been added to the broken limestone to make up for the deficiency in the fine material produced in breaking it. This imported sand was that referred to at p. 162 in describing the manner in which the erosion had taken place in the floor of the aqueduct. As Mr. Barnett had entered upon his duties as Resident Engineer after the contract for the work through this district had been let, he could not say what precedent or circumstances had been taken into consideration in deciding that the local stone was to be used. All fissures met with in the limestone in the cut-and-cover sections had also been filled. Special reference to the filling of the fissures in the Hutton Roof tunnel had only been made as indicating why it had been considered safe to leave the refacing of the centre of the tunnel to the last. The reason why the leakage was so great in the cut-and-cover section No. 1 was, that the limestone rock there, although not specially fissured, was so much shattered that it formed no effectual barrier to water which had found an outlet from the culvert. Mr. Paterson was under a misapprehension in thinking that the rough and honeycombed concrete had been left. No honeycombed concrete had been allowed to remain in the aqueduct as far as it could be discovered by the hacking-off. The expression "quite rough and honeycombed" used in the Paper referred to the surface mortar of the concrete of the side walls, and did not apply to the body of the concrete itself. Should the surface water seriously affect any of the outside concrete not already disclosed by the work of these repairs, this would have to be dealt with according to circumstances.