Discussion.

The President. The PRESIDENT moved a vote of thanks to the Authors.

Mr. Tait. Mr. TAIT exhibited a number of lantern-slides illustrating the execution of the Talla works.

Dr. Deacon. Dr. GEORGE F. DEACON observed that Mr. Tait's Paper was an account of very important waterworks which appeared to have been carried out in an admirable manner, and it was to be hoped that the Author's very careful rainfall-gaugings¹ and stream-gaugings would be continued, and that the Institution would hear something more about them in the future. *Fig. 3* (p. 109) drew attention to a fact often noticed, namely, the dependence of the flow off the ground on past rainfall and not on the rainfall of the same week, or even of the same month. It was to be hoped that Mr. Tait would elaborate that question also. Waterworks-engineers should look into Mr. Tait's Paper with a view to imitating his methods.

With regard to Mr. Barnett's Paper, the Author pointed out that the analyses in Table I (p. 177) showed no change in either the acidity or the hardness of the water due to its passage through the aqueduct, but that scarcely seemed conclusive, because so large a body of water could hardly be expected to be sensibly changed by the small amount of lime it was taking up; at any rate, it was not changed in such a way as to affect the analysis, but that it was changed there was no doubt whatever. A similar thing had occurred in one part of the Vyrnwy aqueduct, except that the tunnel walls were carboniferous limestone in its natural condition, not built work. In the case of the Thirlmere tunnel the analyses showed that the limestone varied considerably in composition, and that led him to ask whether it had been ascertained that the first sample, which contained 10·5 per cent. of siliceous matter, was acted upon in the same manner as the other three samples, none of which contained more than 1·68 per cent. of silica. There was very little alumina, and the carbonic anhydride (CO₂) and lime (CaO) practically made up the difference, and no doubt accounted for the extreme weakness of the limestone when brought in contact with an acid water. In Yorkshire and Lancashire the struggle with acid water had gone on for many years. His own experience showed that the simplest course was to use crushed limestone as one of the elements of the sand in the filter-bed: he used it himself in the proportion of

one-third limestone to two-thirds siliceous sand, and he found that Dr. Deacon. this limestone deprived the water of the power of acting upon other limestone and upon lead, and largely reduced its action upon iron. Filters made with pit-sand containing, as it often did, carbonate of lime in the form of shells, produced less effect of a like kind; and if the filters were properly worked at a rate not exceeding 4 inches per hour downwards, the sand of which they were formed did not become coated and protected from erosive action by the organic coating which occurred in open streams. Filter-beds should be put as high up the aqueduct as was practicable, as the most acid water could be rendered neutral by proper filtration near the source. The limestone in the filter-beds was dissolved and had to be gradually replaced, but the total quantity carried away in the course of a year was very small.

He agreed with Mr. Hill as to the importance of greater care being taken in the observation of rainfall and evaporation: Mr. Tait showed an excellent example of how this could be done; and Mr. Deacon hoped it would be done to a larger extent in future. He would be very glad to see Mr. Hill's proposals carried out, if practicable, but he was afraid there were a great many difficulties in the way. Some corporations and local authorities might be satisfied to spend a little money usefully in constructing the necessary gauges and making the necessary measurements; but it should be borne in mind that when the construction of a reservoir was once commenced, the difficulties increased. In the first place, the works interfered with the natural flow of the water; and when they had been constructed it was necessary to make a debtor and creditor account between the rise and fall in the reservoir, the water drawn off from the reservoir for consumption and for compensation, and the overflow during floods. The matter became rather complicated, and unless the local engineer was a man who had been trained to that sort of work, and took an interest in it, it was abortive. It was done with success in some cases, and it was well that Mr. Hill had drawn attention to the desirability of doing it in a great many other cases. The short time between the inception of a scheme and the commencement of the work was really the time when gauging could be most usefully done. Then, if a gauge could be fixed across the river and properly observed, a comparison between the results and the rainfall on the area, as determined from a sufficient number of gauges, gave trustworthy information of a very important kind. He entirely sympathized with the suggestion to secure government aid, but he was a little doubtful as to the possibility of doing it. Mr. Hill stated that the three-dry-year

Dr. Deacon. period required closer examination. No doubt that was true in one sense, but it was to be hoped that no doubt would be thrown upon the sufficiency of the three-dry-year method of calculation as far as compensation-water was concerned. In that connection, he had some little difficulty in understanding the figures in Mr. Tait's Paper (p. 106), the evaporation, the deduction for the ratio of the driest three consecutive years, and the total mean rainfall. It would seem to be implied that the deduction for the driest three years as compared with the total rainfall should be made after the deduction for evaporation, but he did not think that was what Mr. Tait meant. In the case of the Talla reservoir it would make no difference, because the deduction to arrive at the yield for the driest three years was stated as a fixed number of inches instead of as a fraction; but the transposition might lead to misapprehensions, and it was a mistake that had been made very often, especially in earlier days. According to the accepted method, which he thought had been stereotyped by the late Dr. Pole's lecture to the Institution 21 years ago, four-fifths of the total mean rainfall was adopted as the mean rainfall of the driest three consecutive years, and from this the figure determined as the evaporation was deducted, the remainder being the so-called "available discharge."

Sir Alexander
Binnie.

Sir ALEXANDER BINNIE, Past-President, congratulated the Institution on the fact that at least two of the Papers under discussion touched directly upon the operation of one of the great forces of Nature which engineers were supposed to direct to the advantage of mankind—in fact a force without which all life would disappear from this planet. Water came in the form of rain; and as he had given some attention to the subject he might be permitted to review what was known on the subject of rainfall. People spoke readily of "average rainfall," but what did they mean by it: was it the rainfall of 3 years or 4 years, or of some other period? He had had the honour of presenting a Paper to the Institution in 1892¹ in which he reviewed the rainfall in various parts of the world, giving 152 instances, and deducing from his analysis that a period of at least 30 to 35 years was necessary to establish the average fall for any given place. He was gratified to find that German investigators who had been at work on the same subject had arrived at practically the same result, namely, that not until a rainfall had been observed for 30 to 35 years was it

¹ "Mean or Average Rainfall, and the Fluctuations to which it is subject." Minutes of Proceedings Inst. C.E., vol. cix, p. 89.

possible to say for certain what the average fall really was, assuming that the rainfall was measured throughout that period under practically the same conditions of gauging. If the observations were continued for a longer time, say to 80 or 90 years, that average would not be materially altered. That was the first fact. Engineers often had to construct works in districts where the rainfall had not been observed over anything like 35 years, and consequently they had to make deductions from a known long record to one of a less number of years. The method of doing that had been explained very fully by the late Mr. G. J. Symons, F.R.S., who, he was sure, had been regarded as a friend by every member of the Institution who had worked with him. The average rainfall having been obtained, the next important question was that of fluctuation. It was now fairly well established that, whether in temperate or in tropical climates, the quantity of rain registered annually at a given place would vary enormously. Within the limits of the British Isles, for instance, it would range from 20 inches to 160 inches per annum. But, notwithstanding that range, the fluctuations on either side of the average for each particular station would be practically the same. Consequently, as he had shown in 1892, and as German investigators had since corroborated, behind the apparently confused fluctuations there was a great natural law which kept them within limits. It was now known that the maximum year's rainfall exceeded the average by about 60 per cent., and that the minimum year's rainfall was about 40 per cent. less than the average. The average rainfall of the driest three consecutive years was about 20 per cent. below the average. Of course, in all scientific investigations the deductions were approximate and not absolute; but it might be said that engineers had arrived at the stage of comparative certainty on these points, though the whole question required examination throughout the world before it would be possible to get within a few per cent. of the absolute results. The next question—and the pertinent question raised by the Papers of Messrs. Tait and Hill—was the following: given, say, the rainfall for the driest three consecutive years, how much of that rainfall was available for the purposes to which it was to be applied? The experience of engineers showed that the amount differed in every part of the world. Inclination of the ground, geological formation, and humidity of the climate all affected the quantity of discharge from the ground that might be expected from a given quantity of rain; and therefore it was necessary to study the conditions of the particular drainage-areas under consideration. In the climate of Great Britain the question was exceedingly complex. It had been his

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good fortune, however, to study the subject in India¹ under very simple conditions, on a drainage-area of $6\frac{1}{2}$ square miles, having exceptional means of gauging the flow from the ground. The conditions were simple because, at the end of the hot weather in the middle of June of each year, the gauging began with the drainage-area in exactly the same state of thorough dryness. A few figures from the Paper contributed by him in 1874 might be interesting. In June the rainfall was 6.77 inches and the flow off the ground only 4.7 per cent.; in July the rainfall was 12.7 inches and the discharge 22.7 per cent.; in August the rainfall was 11.8 inches and the discharge 55.8 per cent.; in September the rainfall was 7.99 inches and the discharge 74.4 per cent. It would be seen that the drainage-area, which was originally perfectly waterless, gradually became saturated, until there was a flow off the ground of three-fourths of the rain that fell upon it. In the month of October, when the rains were just dying away, there was a rainfall of 4.37 inches and a discharge of 39.4 per cent., showing that the ground was gradually returning to its state of dryness in the hot weather. The gross result of observations of that particular monsoon was 43.65 inches of rainfall and a discharge from the ground of 40 per cent. During that period of 4 months there were occasionally heavy showers. On the 3rd July, 3.92 inches of rain fell in 24 hours, with a discharge of 16 per cent. of the quantity: on the 16th September there was a fall of 2.70 inches in 3 hours, and the discharge was 98 per cent. of the rain that fell. Turning from that simple case to one of those intricate cases with which English engineers had to deal, the accompanying Table (p. 191) gave the gaugings of the rainfall in the Valley of the Thames for 18 years 1883 to 1900. The records had been prepared by the late Mr. Symons, and gave probably the best average that had yet been arrived at with regard to the rainfall in the Thames Valley. Columns 2 and 6 showed how the monthly rainfall, and the percentage of rainfall discharged, averaged over that period, varied during the year. The gross result of 18 years' gauging of the Thames in the most careful manner showed that 26.38 inches of rainfall might be expected, of which 30.89 per cent. might be utilized as flowing from the ground. The fluctuations throughout the year were attributable to the clouds of winter and the consequent absence of sunlight.

¹ A. R. Binnie, "The Nagpur Waterworks; with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nagpur; and on the Fluctuation of Rainfall in India and in other places." Minutes of Proceedings Inst. C.E., vol. xxxix, p. 1.

RIVER THAMES, 1883-1900.

Month.	1	2	3	4	5	6	7	8	9	10	11	12
		Rainfall. Inches.	Companies' Abstraction (Daily).	Flow over Teddington Weir (Daily).	Daily Natural Flow.	Flow from the Ground.	Evaporation, Per Cent.	Degrees of Temperature.	Hours of Sunshine.	Degrees of Humidity.	Flow from the Ground in Cubic Feet and Gallons per Second per 1,000 Acres.	
January	.	2.20	90.9	2,108.4	2,199.3	Per Cent. 56.30	Per Cent. 43.70	Degrees. 38.4	Hours. 27.7	Degrees. 88.0	Cubic Feet. 1.68	Gallons. 10.51
February	.	1.93	89.4	2,345.6	2,435.0	64.71	35.29	39.2	51.6	85.0	1.86	11.64
March	.	1.75	90.6	1,733.2	1,823.8	58.64	41.36	41.2	93.1	80.5	1.39	8.71
April	.	1.52	92.4	1,104.5	1,196.9	42.98	57.02	46.8	131.7	76.5	0.92	5.72
May	.	1.86	98.7	808.2	908.9	27.54	72.46	52.7	178.4	73.0	0.69	4.33
June	.	1.86	106.0	553.2	659.2	19.34	80.66	59.4	179.6	73.5	0.50	3.15
July	.	2.34	111.6	413.1	524.7	12.65	87.35	62.1	178.8	72.5	0.40	2.51
August	.	2.36	108.0	359.2	467.2	11.18	88.82	61.3	169.8	75.0	0.36	2.23
September	.	2.19	105.5	376.7	482.2	12.02	87.98	57.1	130.7	79.5	0.37	2.30
October	.	3.00	100.0	710.8	810.8	15.27	84.73	48.9	80.9	84.5	0.62	3.88
November	.	2.89	95.2	1,452.6	1,547.8	29.22	70.78	44.2	41.3	87.5	1.18	7.39
December	.	2.43	92.2	1,649.5	1,741.7	39.57	60.43	39.5	22.0	87.5	1.33	8.32
		26.38	98.4	1,128.3	1,226.7	30.89	69.11	49.2	1,235.6	80.5	0.94	5.86

Sir Alexander Binnie.

Sir Alexander
Binnie.

Fig. 1 showed how, as the altitude of the sun became greater, the temperature continually increased, and the humidity of the atmo-

Fig. 1.

RIVER THAMES, 1883-1900.

sphere decreased; hence the enormous evaporation that took place during the early spring and summer months. A complicated case such

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as that led to an appreciation of the feeling of waterworks-engineers that the 12 inches, 15 inches, or whatever it might be, of rainfall which they were in the habit of deducting from what was considered to be the fall of the driest three consecutive years was arrived at purely by approximation, and was founded on no scientific basis. It was the result of judgment to the best of their ability, but distinctly unscientific. He understood that Mr. Hill desired to emphasize the necessity of endeavouring to arrive at some more exact result, and he quite agreed with him. Then arose the difficult question how this end could be achieved. Within the experience of all engineers there were many cases where very accurate gaugings might be made—works in the hands of large corporate bodies who would not expend money on the ascertainment of what might be called economic facts. He had had occasion to say to such corporations more than once that it was as important for them to know the quantity of water that would flow off the drainage-area as it was for their opponents, who wanted to get every possible gallon out of them; and that without the actual facts it was impossible for anyone to dogmatize on the subject. Year by year the water resources of the country became more taxed, and water became more valuable; and the only possible way of arriving at more accurate data was by engineers making it a *sine qua non*, when a corporation was applying to Parliament for powers, that there should be imposed upon them, as one of the conditions on which Parliament granted them private rights over public waters, the obligation in the future to keep accurate scientific records of the amount of water with which Parliament had entrusted them. He saw no other way out of it. To go, say, to the Royal Society and ask that society to take up the matter would be rather beside the question. It was a matter that rested in the hands of engineers who had to promote and oppose Bills in Parliament; and he thought that the only thing they, as professional and scientific men, could possibly do was to make the thing perfectly clear to Parliamentary Committees and thus induce Parliament in future to place under stringent conditions persons granted rights over catchment-areas.

Mr. B. HALL BLYTH, having been for many years engaged in advising landed proprietors and others on the question of compensation-water, desired to make a few remarks about that branch of the subject. Mr. Hill said in his Paper that the water-supply of the country was really a national matter. Whether the water-supply of the country should be a national as against a municipal matter Mr. Blyth did not propose to argue, but he thought that

Mr. Blyth.

Mr. Blyth. everyone would agree that the question of compensation-water was national in the highest sense. Year by year the sources of water-supply throughout the country were becoming fewer, and it became more essential than ever that the greatest care should be given to the question of compensation-water to be sent down the rivers and streams, if the beauty of the country was to be preserved. In Scotland, at any rate, the quantity of compensation-water was firmly fixed, and it would be very difficult before a Parliamentary Committee for any engineer to avoid having to give one-third of the water as compensation. There had been many fights, one of the most important being that connected with the borough of Wishaw. Some years ago Wishaw, a comparatively small town in Scotland, proposed to abstract water for its supply from the highest reaches of the Clyde. The quantity proposed to be abstracted was not at all large, but he was asked by the Earl of Home and one or two other proprietors to oppose the measure and to endeavour to get compensation-water. Under the Bill no compensation-water whatever was proposed, nor was any compensation-reservoir proposed to be erected. The matter was fought in both Houses of Parliament, with the result that Parliament declared that one-third of the water dealt with should be sent down the Clyde as compensation. When he stated that the distance of the nearest point of Lord Home's property from the point of abstraction of water was 40 miles, it would be seen that that case fairly well established a precedent—at any rate for Scotland. That was all very well when a Bill was opposed, but unfortunately there came before Parliament and before Provisional Order Inquiries, many measures so small, and affecting such infinitesimal interests, that no one presumably had any interest in opposing the Bill or the Order. He knew of many cases where Bills had been got through Parliament which either provided for no compensation at all or for very inadequate compensation. He cordially agreed with what Sir Alexander Binnie had said, but he would go farther. Not only should a Parliamentary Committee make the authority applying for Parliamentary powers bound to keep records of the rainfall, but there should also be a Government department to examine every water Bill—as there was to examine every railway Bill—and to see that adequate compensation was sent down the rivers from which water was proposed to be abstracted. After the proportion of compensation-water had been determined by Parliament, it became necessary to ascertain what was the quantity of available water of which one-third was to be given as compensation. Mr. Tait's Paper very accurately described the arbitration proceedings in connection with

the determination of the compensation-water for the Talla district Mr. Blyth. before Mr. Mansergh. The only question to be argued had been whether any deduction was to be made from the figures of the recording rain-gauges in order to arrive at the available water. Every engineer acting on behalf of a corporation was bound to look at the matter from the point of the weakest link in the chain; he was bound to tell his clients what was the minimum quantity of water he would guarantee to deliver; and after having taken rain-gaugings and made allowances for years past in other districts, he then had to deduct the assumed quantity of one-fifth or one-sixth, in order to arrive at the yield of the driest three consecutive years, because that was the measure of the supply he could guarantee to the town which employed him. From that fact alone an error had crept in with regard to compensation. Compensation-water had been calculated at one-third of the quantity that the town could be guaranteed, and that was entirely wrong. Although the engineer said that was the minimum he could supply, he did not for a moment limit himself to taking that quantity. He had the entire control of the whole drainage-area, and although the quantity shown by the driest three consecutive years might be 1 million gallons per day, in ordinary years there might be 2 million gallons per day available, and there was nothing to prevent the engineer from utilizing that quantity of water. Even if he did not, Mr. Blyth could not for a moment see why landed proprietors, municipalities, and the nation should have their compensation fixed upon the smallest quantity of water that could be got out of a certain district. He knew he would be at variance with the great water-engineers, because their business was to provide water for communities at the lowest possible cost, and if effect were given to his principle it would mean raising the reservoir-embankment 3 feet or 4 feet. That was simply a matter of cost to the municipalities; but his point was that it was very important for the nation that every drop of water which was necessary for keeping the rivers and streams up to their proper level should be conserved; and he asked all water-engineers and everybody connected with water-supply to consider what he had said.

Dr. H. R. MILL desired to say a few words about the methods Dr. Mill. for determining the amount of available rainfall in areas for the supply of towns. When Sir Alexander Binnie spoke out of the depth of his great experience, Dr. Mill felt there was very little indeed to add, except it might be an expression of gratification at the high esteem Sir Alexander preserved for his old friend Mr. Symons. There were, however, one or two practical points to which

Dr. Mill. it might be desirable to call attention once more. He was glad to find in Mr. Tait's Paper that he had set out on the Talla drainage-area rain-gauges of what were known as the Meteorological-Office and Snowdon patterns, because those gauges had proved to be the most satisfactory for the measurement of rain, especially when they had to remain exposed for a considerable time without a visit from the observer. It was always better to observe and record daily, if possible, but much information could be obtained from monthly records. Some years ago the favourite rain-gauge on water-supply grounds was the Glaisher gauge, an excellent instrument when new, but having the defect of being somewhat complicated, as it consisted of many pieces of copper soldered together. Recently, in going over several long-established rainfall-stations where Glaisher gauges were in use, he had found them fallen into a state more or less of decay, and in every instance when they began to fall into disrepair they caught too much rain. Every other form of rain-gauge when it began to err caught too little rain. It was hardly necessary for him to point out to engineers that it was sometimes much against their interest for a rain-gauge to catch more rain than should properly fall into it. Therefore Glaisher gauges ought to be very carefully supervised and repaired as soon as the slightest appearance of decay appeared on the soldering; or, still better, they ought to be immediately superseded by gauges of a standard pattern. The placing of the gauges on the drainage-area was perhaps the most difficult question of all, and he was sorry Mr. Tait did not deal more explicitly with that matter in his Paper. He said, no doubt correctly, that the gauges were so placed as to yield the true rainfall over the area. Experience showed how difficult it was so to place gauges, and how very rarely they were found set out in a drainage-area in such a way that the arithmetical average of their readings gave the true rainfall of that area. As a rule he found it necessary to take other considerations into account, especially the configuration of the district. He quite agreed with Mr. Tait that it was not desirable to apply any percentage correction for elevation, because the variation of rainfall with height above sea-level was very complicated, depending not only upon the height of the land, but also on the form of the land in relation to the prevailing wind. Accepting Mr. Tait's statement that the mean of the gauges gave the actual average rainfall on the land, there was another point to consider: how far did the average of the 7 years in question differ from the true average rainfall, which, as Sir Alexander Binnie had said, was practically an average of 30 to 35 years? Out of curiosity Dr. Mill had examined some of the older records, not quite

in the vicinity of the gauges under discussion, because there were Dr. Mill. no records in the immediate vicinity; in fact, the Talla ground was just one of those cases in which the application of the Newcastle clause for the determination of the rainfall by observation for 7 consecutive years was absolutely necessary. The nearest rain-gauges, and the best attempt he could make to determine the ratio, showed him that the rainfall determined from the 7 years 1896-1902 differed by only about 2 per cent. from the long-period average. He thought the difference of 4 per cent. settled by the arbitration was somewhat too large. On the other hand, he thought the deduction of 12 inches was somewhat too small. It had been very clearly established that the safest value to allow for reduction to the driest 3 years—a perfectly safe one, he believed—was one-fifth. Therefore he would make the available rainfall of the Talla ground 36 inches, instead of 38 inches as determined. That was not a large difference considering how unknown the rainfall had been before the observations were commenced. He was very happy to find that stream-gaugings were being kept, so that at the end of a certain number of years it would be safe to draw a deduction as to what portion of the rainfall was actually coming off the land. He was glad also that the rain-gauges were being kept up, because it could be assumed that the computed average would be subsequently compared with the actual average over a long series of years. The evaporation-gauge was an extremely important adjunct which he would like to see in operation at every large waterworks; at present there were far too few evaporation-gauges in existence. The observations were comparatively simple. Although something was known of evaporation from a water-surface, practically nothing was known of the far more important matter, evaporation from a surface covered with vegetation, which was the thing that really determined the loss over a catchment-basin or the difference that must necessarily exist between the discharge and the rainfall.

With reference to Mr. Hill's Paper, he was strongly in agreement, purely from a meteorological point of view, with the suggestions Mr. Hill made. The information Mr. Hill desired would be extremely valuable from a great many practical as well as theoretical points of view, and he would like to see the Local Government Board or other public department take up the matter. The system of voluntary rainfall-observation in Great Britain was the best existing in any country in the world, but still it was just in those areas where they were most wanted for practical purposes that the observations were totally lacking, because it was in the uninhabited regions that the best water was collected for supply

Dr. Mill. purposes, and in those regions there were no natives to be interested in the rainfall. He would be glad if anything came of the proposal put forward by Mr. Hill. If it were possible to secure retrospective action with regard to the works for which powers had already been given, then it would be quite reasonable to ask that in future Bills instructions should be given for keeping an exact record of the rainfall and of the water flowing off. So much of the country had already been parcelled out for water-supply purposes that it was important from a national point of view to know the particulars of those regions as well as of the regions that remained to be applied for—which were rapidly diminishing in extent.

Mr. Hawksley. Mr. CHARLES HAWKSLEY, Past-President, concurred with Mr. Hill in the desirability of obtaining the information set forth as requisite in his Paper. With reference to the utilization of watersheds, what Mr. Hill put forward was no doubt theoretically good, but it was hardly workable, at all events in England. He also thought that if drainage-areas were parcelled out by some Government authority in the way that had been suggested, much waste of valuable water might result and great hardship be done, particularly to small communities. The persons who parcelled out the water for the whole country could not foretell the growth of population and the requirements of water for many years to come, and therefore drainage-areas which otherwise would be utilized would be left awaiting a growth of population in some particular town, which might never occur. As to making observations of rainfall and the flow of water off the ground, it had been said that few public bodies would incur the necessary expenditure, and that was even more the case with regard to public authorities. His own firm happened to be advising two water-companies, one in the south and the other in the north of England, who had authorized a certain expenditure for the collection of such valuable information. Not only had rain-gauges been established and regular observations made, but stream-gauges had been put down for determining the flow off the ground. In the case in the south the stream-gauges would probably deal, if not with the maximum flood, at any rate with the greater part of the floods, because the form of the streams lent itself to the formation, at a moderate cost, of gauges that would effect that object. One stream, for instance, drained an area of about 700 acres, and the range with the gauge went up to 82 million gallons per day, representing a flow of about 0·22 cubic foot per second per acre. Another gauge on the same watershed dealt with about 1,500 acres and the range was as much as 132 million gallons per day, equal to nearly two-thirds of the former flow per second per acre.

Those gauges, together with the recording instruments, etc., had cost Mr. Hawksley. £300 to £400 each, including the weir across the stream, the gauge itself, the 8-day recording instrument, and the house in which it was placed. In the north the circumstances were different, and much larger areas had to be dealt with. One drainage-area was rather less than 5,000 acres in extent, and the gauge on the stream had a range of 92 million gallons per day, representing only 0·4 cubic foot per second per acre. That was because the valleys in which the gauges were placed were rather flat in cross section, and to put up a gauge to deal with the entire floods would have entailed very considerable expense, especially if a free overfall was to be obtained even for large flows of water. In addition to the one dealing with nearly 5,000 acres, there were in that case two others, dealing with about 1,500 acres: these two had a range of 40 million gallons per day, equal to 0·05 cubic foot per second per acre of drainage-area. Those gauges were not supposed to deal with the flood-waters; they had been put down mainly for the purpose of ascertaining the dry-weather flow, and they answered admirably for that purpose. When the observations had been continued for some time—all the gauges he had mentioned had been erected within the last 2 years—he hoped some useful results would be obtained, at all events with regard to the dry-weather flows. For several years one of the companies had had numerous gauges studded over the drainage-area for ascertaining the rainfall, but they had since been somewhat reduced in number, those gauges having been removed which were shown to accord fairly with the records of the gauges still left. In the northern case not only were the principal streams observed, but there was also an instrument for recording the depth of water flowing over the weir at the head of the by-wash. Of course, any records of that kind were liable to be interfered with at times by the opening of the main valves, which let out a quantity of water that could not readily be gauged; but that was only an occasional circumstance, and although it might vitiate the records of one or two years, it would not permanently invalidate the information obtained. The formulas laid down by Mr. Hawksley's father had hitherto been found to give very fairly accurate results, and no hesitation need be felt in continuing to make use of them, although of course they did not deal with all the niceties that Mr. Hill proposed should be dealt with when other observations were obtained and applied. He agreed with what had been said as to the indebtedness of all waterworks-engineers to the late Mr. Symons for his rainfall-observations and for that valuable annual, "British Rainfall," which Dr. Mill was now carrying on. With regard to the basis of computation of the quantity of

fr. Hawksley. water to be given as compensation—usually one-third where mills had to be provided for, and one-fourth where only fishing-interests had to be met—it must be one-third or one-fourth of the entire available rainfall, the district to be supplied taking the other two-thirds. He agreed that something between 30 and 40 years of observation was necessary to indicate the true mean rainfall; but, whatever the period, it should comprise an equal number of dry cycles and wet cycles. Manifestly, if there were two wet cycles in the period and only one dry cycle, too large a rainfall would be obtained. The discharge, in regard to which Sir Alexander Binnie had given some very interesting figures, depended largely also on the way in which the rain fell. If rain fell on every day in the month very little would run off, but if the same quantity of rain fell in 2 or 3 days, a larger proportion would run off. He did not agree with the view that the number of inches assigned to evaporation was a mere guess, because it had been determined by his father from observations of the quantity of water really impounded in reservoirs from given rainfalls. Therefore he thought it stood on a better foundation than guesswork. It was true that, as Mr. Blyth had said, engineers could, if they chose, impound the whole of the water, although the compensation was determined after a deduction of one-fifth or one-sixth from the average rainfall in order to determine the rainfall of the driest three consecutive years; but here the money question came in, which operated in favour of the riparian owners, because it seldom paid to impound more than four-fifths of the average rainfall. Although theoretically it could be done, monetary considerations prevented its being carried out in practice.

Mr. Barnett's Paper showed that limestone was not a suitable material for concrete which was liable to be attacked by a soft water. A culvert could be repaired, but what was to happen to a concrete trench—what would be called a puddle-trench if puddle were used—if the concrete were made with limestone? Gradually it would be dissolved away, although the process might take many more years than it would take in a conduit, because in the conduit fresh water was always being presented to the limestone, whereas the change of water in a concrete trench or barrier would be very slight. Possibly if the cement mortar used with the limestone had been made with sand not containing any limestone, the process of dissolution might have been somewhat retarded.

With regard to Mr. Tait's Paper, he would only ask whether the cost per million gallons of storage, given on p. 112, included the cost of the railway, which was stated separately.

Mr. J. A. BALFOUR pointed out that Mr. Tait drew attention to Mr. Balfour. the flatness of the inner slope of his embankment, but as he made no special mention of the material being unsuitable for such work, it would be interesting to know his reason for making it so flat. No special means of consolidation seemed to have been adopted except that due to the tracks for hauling earth, and it would be interesting to the engineer engaged in earthwork-construction to know approximately what the amount of settlement had been at the highest part of the dam. The Paper did not state the period occupied in carrying out the earthwork, which of course affected the settlement. Mr. Balfour had always had to allow something for settlement, which largely depended on the time taken to do the work, and on the nature of the earth.

Mr. Barnett's Paper described an interesting method of plastering the inside of an aqueduct, but Mr. Balfour had adopted a method of doing practically the same thing when the work was being carried out in the first place. The men who were laying the concrete were provided with sheet iron, varying in size according to the nature of the work, and this sheet iron was placed inside the shuttering, about 1 inch or 2 inches from it. Between the sheet iron and the shuttering, mortar was deposited similar to the concrete mortar, and at the same time the ordinary concrete was put in on the other side. About every foot or so the sheet iron was drawn up and the concrete rammed. Plastering done in that fashion did not scale off, and when such work was broken up it was impossible to say where the plaster began and the concrete ended. He had adopted that method in Ceylon in two or three cases, and had found that the work was quite water-tight. In carrying out cheap work, so long as good mortar was used for the plastering, so that a water-tight facing was obtained, the quality of the concrete at the back did not always matter.

Mr. R. B. BUCKLEY thought it might be interesting if he briefly Mr. Buckley. described what had been done in another country with regard to gauging. He had visited Spain at the beginning of 1906 with the object of inquiring into the possibilities of irrigation from the River Guadalquivir; and he had found that about 16 years ago the Spanish Government issued detailed instructions which, had they been carried out, would have given, for almost every catchment-area in Spain, all the information Mr. Hill desired to see collected in England. The whole work was to have been carried out at the expense of the State. The Spanish Government made excellent laws on many matters—their laws with reference to irrigation were certainly very

Mr. Buckley. good—but nobody seemed to care very much whether the laws were carried out or not, and the result of the law passed 16 years ago was hardly what might have been expected. However, in the valley of the Guadalquivir the observations had been recorded, and, speaking from memory, he thought there must have been at least twenty stations in that valley where gauges had been fixed and readings made for 10 or 12 years. The discharges had been gauged and corrected to the gauges, and very voluminous records had been obtained, showing all the discharges from various points of the catchment of the river and its tributaries. If the Government of a comparatively poor country like Spain could issue such orders, and to a certain extent get them carried out at the cost of the State, it was possible, if similar orders were issued in England, that they might be carried out and be productive of good. There were some respects in which the data for the Guadalquivir were not very accurate, but they might be of use to those who were interested in the connection between the discharge from a catchment and the rainfall. The following statement showed the ratio of discharge to rainfall in nine different catchments, all lying in the basin of the Guadalquivir and its affluents. It must be remembered that the rainfall was the general fall on the whole catchment of the river; there were no data from which the rainfall of each particular basin could be determined. In the worst year the discharge of the entire basin of the Guadalquivir was only 9 per cent. of the gross rainfall, and in the best year it was 50 per cent. It might strike some engineers as curious that the worst discharge was by no means in the year of worst rainfall, nor was the best discharge in the year of the best rainfall; but of course there was an explanation for that. If the records which Mr. Hill desired to see collected in England were obtained, Mr. Buckley hoped that attention would be given to the important matter of systematic and detailed scrutiny of the records obtained. Those whose duty it had been to pore over gauge-readings and statements of discharge must have been struck by the fact that, where there had not been rigid supervision, the records were often unreliable. Some years ago he was in Central Africa examining the records of the gauge-readings of the Victoria Nyanza, and on one page he came to a blank. On his asking the reason, the gentleman in charge said that the gauge had been knocked down by a hippopotamus. Of course, that was a thing which could not be helped; but Mr. Buckley asked if the gauge had been put up again, and the reply was that it had. When asked how he had fixed the zero, the gentleman replied that he had nailed up the gauge without any bench-mark to refer to; and it was rather questionable whether the

Mr. Buckley.

Name of River	Guadaluquivir				Genil	Guadalimar	Guadabulbon	Guadiana Merur.
	Calancha	Menjibar	Cordoba	Palma del Rio	Cantillana	Palma del Rio	Baeza	Los Priros.
Site of the Gauge on the River								
Area of the catchment above the gauge in Square Miles.	3,143	5,875	9,239	12,127	17,020	3,447	370	2,712.
Year.	Percentage of Gross Discharge to Total Rainfall of the Year.							
1888	..	47	..	..	50	36	..	..
1889	..	32	..	26	22	33	..	..
1890	..	17	..	14	16	21	29	..
1891	..	12	..	16	19	19	16	..
1892	..	38	..	27	29	26	80 ²	..
1893	23	12	13	13	15	25	11	..
1894	17	9	9	9	9	15	7	..
1895	29	23	21	22	27	35	15	..
1896	19	20	16	16	18	27	30	..
1897	16	20	21	26	27	16	24	..
1898	14	17	13	11	10	13	18	6

¹ The rainfall here given is the average of eleven stations in, and near, the whole basin of the Guadalquivir.

² A very doubtful observation.

Mr. Buckley. zero of the gauge was at the same level as before—a matter which did not seem to be regarded, on the spot, as one of much importance.

Mr. Martin. Mr. A. J. MARTIN observed that, in stating that the range of depth for a weir for quantities varying between 1 and 2,500 would be between 1 and $(2,500)^{\frac{1}{3}}$, or between 1 and 184, Mr. Hill was referring, of course, to a notch with a flat sill; but if instead of using a notch with a flat sill a rectangular V notch were used, the range of depth to pass a given quantity would be greatly reduced; instead of being between 1 and 184 it would be between 1 and 22·9. On the other hand, the depth involved would in some cases be inconveniently increased. Mr. Martin had worked out the actual depths for a case in which the minimum flow was 100 cubic feet per minute, and the maximum (at the rate of 2,500 times the minimum) was a quarter of a million cubic feet per minute. The depth in a right-angled V notch for the smaller quantity would be 10·15 inches, and for the larger quantity 19 feet 4 inches. That depth would, doubtless, be inconvenient in some cases. The limiting consideration would generally be the depth to which it was safe to impound the water above the gauge. His object in speaking was to propose a form of gauge—which, so far as he knew, was novel, being a compromise between the ordinary right-angled V notch and the flat gauge—in the shape of a V much flatter than a right angle, the precise slope of the sides to depend on circumstances. By way of illustrating his proposal he had worked out the depth, taking the quantities of which he had just spoken, for a V notch in which the width at the top, instead of being twice the depth, as in the right-angled notch, was ten times the depth. In such a notch as that, 100 cubic feet per minute gave a depth of 5·33 inches, and 2,500 times that quantity gave a depth of 10 feet 2 inches. These were both moderate depths, and even with the smaller flow the depth was of such magnitude as to be gaugeable with considerable accuracy. For the purpose of this calculation he had used the formula, which it might be well to verify by experiment, $Q = 1·525 h^{\frac{3}{2}}$, in which Q was the flow in cubic feet per minute, and h was the depth of flow in inches. Mr. Hill complained that published accounts of thorough and reliable experiments on the yield of collecting-areas did not exist. But Mr. Buckley had called attention to one such set of records, and Mr. Martin would like to call attention to another set which was in the possession of the Institution, but which he was not sure was known to the members generally. The Institution received annually the reports of the Massachusetts State Board of Health. One section of these reports referred to an examination of certain

RAINFALL UPON SUDBURY RIVER WATERSHED AND FLOW OF SUDBURY RIVER FOR THE YEAR 1905.

Condensed from the 37th Annual Report of the Massachusetts State Board of Health.

Drainage area of Sudbury River above gauging-point 75.2 square miles.

Month.	Rainfall. Inches.	Excess or Deficiency.		Flow of River.			Percentage of Rainfall Collected.	
		Inches.	Per Cent.	Cubic Feet per Second per Square Mile.	Million Gallons per Day per Square Mile.	Excess or Deficiency per Cent.	1905.	Mean for 31 Years.
January . . .	5.26	+1.02	+ 24.1	2.182	1.410	+ 15.3	47.8	51.5
February . . .	2.20	-2.07	- 48.5	0.510	0.330	- 81.8	24.2	68.9
March . . .	3.15	-1.40	- 30.8	3.864	2.497	- 15.9	141.5	116.6
April . . .	2.72	-0.86	- 24.0	2.543	1.643	- 21.7	104.2	101.3
May . . .	1.31	-1.97	- 60.1	0.460	0.287	- 73.3	40.4	60.6
June . . .	5.00	+1.85	+ 58.7	0.723	0.467	- 10.2	16.1	28.5
July . . .	5.47	+1.74	+ 46.6	0.275	0.177	- 7.7	5.8	9.2
August . . .	2.70	-1.31	- 32.7	0.177	0.114	- 59.9	7.6	12.7
September . . .	6.88	+3.45	+100.6	1.928	1.246	+360.0	31.3	13.6
October . . .	1.54	-2.60	- 62.8	0.245	0.158	- 68.0	18.3	21.3
November . . .	2.07	-1.82	- 46.8	0.431	0.279	- 67.2	23.3	37.6
December . . .	4.01	+0.19	+ 5.0	1.873	0.887	- 17.5	39.5	50.2
Year . . .	42.31	-3.78	- 8.2	1.230	0.795	- 25.8	39.5	48.9

GREATEST, LEAST AND AVERAGE FLOWS IN 1905 FROM THREE WATERSHEDS.

Flow in cubic feet per second per square mile.

River.	Drainage-Area, Square Miles.	Average			Greatest Week's Average.			Least Week's Average.		
		Average for 31 Years.	Average 1905.	Below Average, Per Cent.	Week Ending	Flow.	Above Year's Average.	Week Ending	Flow.	Below Year's Average.
Sudbury River . . .	75.2	1.658	1.230	25.8	26 March	6.012	389%	4 June	-0.711	158.0%
South Branch Nashua River . . .	119.0	..	1.434	..	2 April	8.302	479%	23 July	0.338	76.4%
Merrimack River . . .	4.664	..	1.197	..	2 April	8.679	625%	1 Jan.	0.414	65.4%

Mr. A.J. Martin

Mr. Martin. AVERAGE FLOW OF SUDBURY RIVER FOR PERIOD OF 10 YEARS, INCLUDING DRIEST THREE CONSECUTIVE YEARS.

	Year.	Cubic Feet per Second per Square Mile.	Above Mean for 31 Years.		Below Mean for 31 Years.	
			Cubic Feet per Second.	Per Cent.	Cubic Feet per Second.	Per Cent.
	1876	1.756	0.098	5.9	..	..
	1877	1.877	0.219	13.2	..	..
	1878	2.246	0.588	35.5	..	..
Driest 5 years	1879	1.383	..	..	0.275	16.6
	1880	0.894	..	..	0.764	46.1
	1881	1.515	..	..	0.143	8.6
	1882	1.334	..	..	0.324	19.5
	1883	0.825	..	..	0.833	50.2
	1884	1.747	0.089	5.4	..	..
	1885	1.394	..	..	0.264	15.9
Mean flow for 31 years (1875-1905)		..	1.658	..	..	..
Driest 3 years	Total	..	3.674	..	..	..
	Mean	..	1.225	..	0.433	26.1
Driest 5 years	Total	..	5.951	..	..	..
	Mean	..	1.190	..	0.468	28.2

N.B.—It will be seen that the mean flow for the driest 5 consecutive years is less than that for the driest 3 years.

rivers within the State, three of which, the Sudbury River, the south branch of the Nashua River, and the Merrimack River, had their flow gauged periodically and carefully. The rainfall throughout the State was gauged, and the discharge from the various watersheds was worked out. He had prepared the accompanying brief abstracts of the figures for 1905.

Mr. Hunter. Mr. WALTER HUNTER remarked that the Talla waterworks appeared to have been well designed and economically carried out. Of course, where no clay was to be found on the site of the reservoir, the railway-line was a necessity. When he was in Johannesburg, laying out a water-supply for the Rand, it seemed to him desirable to run the line of pipes along the line of the existing railway; although that necessitated rather a long pipe-line, it would save a great deal of expense, it would enable the materials to be carried at a much cheaper rate, and it would afford greater facilities for making repairs. The rainfall and discharge of the Talla district appeared to have been very carefully considered. Mr. Blyth seemed

to be not quite satisfied with the award he had obtained, but, inas- Mr. Hunter.
much as it had been given by Mr. Mansergh, no doubt justice had been done. *Fig. 3* was very useful and instructive, and gave the kind of information which Mr. Hill asked for in his Paper. Sir Alexander Binnie's figures were also very valuable. No doubt rain when it first fell did not have much effect upon the flow of the streams. In South Africa at the end of the dry season the water-courses had no water in them at all; he had been able, at Standerton to walk across the River Vaal, and at Viljoen's Drift to drive across in a Cape cart upon stepping-stones, although at times floods of about 43,000,000 gallons flowed down in a single day. The land for the Talla scheme appeared to have been bought for about £6 per acre, which seemed remarkably cheap, particularly as the Trustees also derived a return of something like 0·8 per cent. upon the whole cost from the 300 acres let as pasture-land above the site of the reservoirs. He presumed that the £251,000 given as the cost of the reservoir did not include the cost of the railway. Adding that, the cost was £111 per million gallons including the railway, or £90 excluding the railway. Therefore he congratulated the engineers upon the way in which the work had been carried out, because it was difficult to say, in the face of such figures, that any unnecessary expenditure had been incurred. He was struck, however, with the fact that the puddle wall was said to be 10 feet thick at the top and about 32 feet at the ground-level. No doubt the engineers had had good cause for making it of that thickness, but in the Staines reservoir the puddle wall was 6 feet thick at the top, 7 feet at the ground-level, and 4 feet where it entered the London clay. The height of the bank was about 35 feet, and the greatest depth of the excavation below the ground-level was about 38 feet. On being tested those reservoirs had proved to be so watertight that when there was a heavy fall of rain it was necessary to let off some of the water. The slopes in the Talla reservoir were 4 to 1 inside and 3 to 1 outside, while at Staines the slopes were 3 to 1 inside and $2\frac{1}{2}$ to 1 outside; but at Staines there was excellent material in the shape of gravel, and no difficulty had been experienced in regard to stability of the banks. He would like to know on what grounds the 36-inch and other valves of the Talla works had been made entirely of gun-metal when the upstand was of cast iron. The stone pitching on the internal slopes of the Talla reservoir had cost 16s. per square yard. The concrete slabs 5 inches thick at Staines, which had proved perfectly efficient, cost only 4s. 6d. per square yard. With regard to the weir, it would be interesting if the Author would say what depth of water he calculated would run

Mr. Hunter. over the weir with the greatest rainfall recorded. Mr. Hunter ventured to think that the lining of the tunnels was a wise precaution to take. The plan of laying 9-inch pipes under the invert to carry off the water had been adopted also in the aqueduct at Staines. The course adopted in connection with the Carsewell tunnel showed the advantage of dealing liberally and equitably with the contractor. He hoped that the valuable Tables accompanying the Paper would be continued. The greatest evaporation recorded in Mr. Tait's Paper was 19.75 inches per annum. Observations made at Johannesburg by Mr. G. P. B. Andrews, M. Inst. C.E., showed that the evaporation there was something like 62 inches in the year, a fact which might be useful to those who had to construct water-works in hot climates. With regard to Mr. Tait's remark that investigations for the detection and checking of waste throughout the Edinburgh water system still continued to occupy the attention of a special staff of men day and night, no one could exaggerate the importance of preventing waste. He had had a special experience of that importance in connection with the Grand Junction Water-works Company, of which for some years he was the Engineering Director. On undertaking the work he had found that the company was supplying at the rate of 49.6 gallons per head per day, and he had naturally felt that that was an excessive amount. He had always been met by two objections—first, that it was much cheaper to pump water than to carry out inspection, and secondly, that the Grand Junction district was an exceptional district. He had admitted the latter contention, because the district covered a large part of the West End and south-west of London, lying between Hampton and Piccadilly Circus, including such districts as Mayfair, and contained thirty-two clubs, the supply of which, upon the average figure of seven persons per supply, amounted to 1,153 gallons per head per diem, and eleven hotels, the supply of which amounted to 1,190 gallons per head per diem. There had also been a feeling that if rigorous inspection were carried out some householders in Mayfair would be offended, and a good many of them were connected with one branch or other of the legislature. He had felt, however, that these were not sufficient reasons for allowing matters to remain in an unsatisfactory position, and he had persuaded the Board at length to undertake waste-inspection guided by Deacon meters. In issuing instructions at the time he had impressed upon all members of the staff the absolute necessity of carrying out the inspection in the gentlest manner possible, and that persuasion rather than force should be used in getting people to allow the inspection. The staff had been directed to point out that it

was undertaken in the consumers' interest, and for the sake of Mr. Hunter. husbanding the supply of water and preventing waste, which did them no good and did the rest of the community a great deal of harm. Accordingly a Waste Department had been instituted. A few Deacon meters had been placed in the district before, but in such a matter spasmodic efforts were valueless; and, moreover, meters were of no use except as pointing out where the waste took place. The results achieved were the following, but it should be noted that part of the saving was due to an alteration in the method of taking the condensing-water from some of the engines:—In 1895, there were 59,780 supplies with a population of 387,372 persons. In 1904, the supplies numbered 73,688, and the population 477,498. In 1895, with the smaller population, the supply was at the rate of 19,219,000 gallons per day; in 1904, after inspection had been in force, the 477,498 persons, or 90,000 additional, were supplied at the rate of 16,966,000 gallons per day, the rate per head per day having been reduced from 49·61 gallons to 35·62 gallons. If the supply in 1903 had been at the rate of 49·61 gallons per head per day, as in 1895, the average daily supply in 1903 would have been 23,688,000 gallons, or 39 per cent. more than the actual daily supply given. Of course that had caused a large increase in the net profit of the company, but it had had a still more important effect upon the position of the company since it had shown that if the supply were reduced, as he believed it would be, to 33 gallons per head per diem, the works and the plant could supply an additional population of 50 per cent. without any increase in the capital account, except for service mains. He wished to impress upon all, particularly young water-engineers, the great necessity of looking to the amount of the supply, because that was one of the critical matters to be considered by any engineer who had to design or administer waterworks.

He considered that Mr. Barnett had shown praiseworthy resource and thoroughness in dealing with the Hutton Roof aqueduct, and his Paper conveyed a lesson on the necessity of considering local conditions before deciding what materials should be used.

Mr. Hill's Paper threw out valuable hints as to the collection of information, and it would be instructive if the Author would furnish instances in which too much compensation-water had been originally given, and had had to be bought back eventually at a high price. No doubt many engineers possessed a good deal of valuable information in regard to rainfall and discharge, but probably they were not altogether willing to publish it, because possession of it necessarily rendered their advice more valuable to those who consulted them. With regard to the general subject of

Mr. Hunter. collecting information, he quite agreed that the question was a national one, because, since the population increased and the water-supply continued practically the same, it was very desirable, from a national point of view, to be able to utilize each watershed to the utmost. At the same time, the local authorities had also a strong interest in the question, and possibly the expense to which Mr. Hill had alluded, and which was the great obstacle in the way, might properly be borne by the county councils, aided, perhaps, by a grant from the Imperial Government.

Mr. Eaton. Mr. E. M. EATON stated that the subject dealt with by Mr. Hill was one to which he had given great attention for many years, and he thought he would be able to put before the Institution some results which might tend to show that the rather pessimistic tone taken by Mr. Hill was not justified. He did not think Mr. Hill had made out a case that the engineering profession was so utterly wanting in information as his Paper seemed to indicate. Mr. Hill said that very little was known about the yield of drainage-areas, that in effect very few observations had been made, and that the knowledge on the subject was nearly in a state of chaos. With all respect to Mr. Hill, he begged to differ, on the grounds of both history and professional knowledge. With regard to history, the principles of the matter had been fully understood and acted upon by the late Mr. Thomas Hawksley, Past-President Inst. C.E., who had elaborated the subject, formulated it, drawn deductions, and laid down rules which water-engineers were acting upon to the present day. Those rules had been modified in some small particulars, but the main principles established by him had been justified by the success of the works which he constructed; and those engineers who followed him, perhaps a long distance behind, but who did follow him, acting on the same lines, had also been able to construct works which had stood the test of time and the searching test of all waterworks—the periods of consecutive dry years. There was one water-undertaking with which he was necessarily perfectly familiar, because he had been the engineer, either resident or consulting, since the year 1869; and it was the investigation of the records of that undertaking that had led him to go into the matter as far back as the early seventies, and to put some results before Mr. Hawksley which differed slightly from those that gentleman had set forth. At a later stage, having a Bill of great importance before Parliament, Mr. Hawksley asked him to visit the majority of the gravitation waterworks in England, and to verify, as far as possible, the deductions he had drawn from his earlier observations. Mr. Eaton did so, and as the result he was in a position to say that

the rules that Mr. Hawksley had laid down were as applicable Mr. Eaton. to-day as when he first devised them. Mr. Hill suggested that an immense amount of measuring-apparatus was required. Mr. Eaton agreed with Mr. Hill that one thing was paramount: it was necessary to have a fair indication of the rainfall upon the drainage-area. But as to gauging the streams, it might be a very useful thing when laying out a new scheme, but it was by no means essential. The final result could be obtained in a far better way by observations on existing works. *Fig. 2* was his working-diagram, made for the Sheffield waterworks about 1873 or 1874, of the three consecutive dry years 1863-4-5. The diagram represented the rise and fall of the water from the beginning of the year 1863 to the end of March 1866, and it would be seen that during the whole of that period the water never ran over the by-washes. The diagram related to a drainage-area of practically 5,000 acres, and during the whole of that period the reservoirs stored the water, every drop of water that went out of them being measured. The rainfall had been taken from one gauge, and he was bound to say that if that gauge had been put as Mr. Hill suggested, at the end of the reservoir-embankment, and if no other test had been made to ascertain whether it represented the yield fairly, it might have led to very fallacious results; but many tests had been made upon that watershed to see how the gauge differed from the rest of the watershed, and the two had proved to be singularly near. At various times in dry seasons, when the whole of the water could be stored and measured without any complication by floods passing water away and thus introducing matters of dispute as to the quantities of water caught, he had taken out the difference between the amount that came into the system of reservoirs as indicated by the rain-gauge, verified by other gauges, the record being always the standard gauge at the station known as the Redmires, 1,110 feet above sea-level, and in immediate proximity to the high-level system of reservoirs. In the year 1851 no water whatever was lost, and the difference between the quantity of water falling on the watershed, as indicated by the rain-gauge, and the quantity actually measured out of the reservoir was 15·05 inches. In 1863-4-5, the whole of the water during the 3 years, or rather more, was received into the reservoirs and was all measured, and the loss in those 3 years averaged 15·01 inches per annum; that was to say, it agreed within 0·04 inch of the year 1851. In 1884 the loss was 15·47 inches, but in that year a little water went away in the early summer as flood-water, and although it was passed over a mill-gauge and measured, there was no certainty that the figure was accurate, and it might be wrong to the extent of $\frac{1}{4}$ inch. In 1905,

Mr. Eaton. on the same drainage-area, the loss was 15·95 inches, but on the whole of the Sheffield watershed the loss was 15·55 inches. All that

went to show that about 15 inches could safely be taken for calculating the deduction to be made from the quantity of rainfall

obtained during the driest three consecutive years. All the Sheffield Mr. Eaton. reservoirs had been constructed on that method of calculation, and they had never failed. Since 1869 Sheffield had received a constant supply without the intermission of a single day. In the adjoining watershed of Rotherham, a rather flat country, during the two consecutive dry years 1893-4 the losses by evaporation and absorption had been found to be 18·56 inches. The watershed to the north-east, the source for the Doncaster works, during the three consecutive dry years 1885-6-7, had shown a loss on the average of the 3 years of 22·3 inches. Those were all actual measurements, without any assumption. The only thing open to question was whether the rain-gauges upon which the calculations were based fairly represented the rainfall over the whole of the drainage-areas. At Sheffield numerous observations had been made, and he had no doubt whatever that the standard gauge there, which had been working since the year 1836, fairly represented the true quantity; and he was equally confident that 15 inches was a fair and proper figure to take for such a drainage-area as that of Sheffield. He was fairly confident also that the losses of the other two works, Rotherham and Doncaster, were represented by their respective figures. At Northampton, when Mr. Charles Hawksley completed the reservoirs there, observations were made for a year, indicating the loss of 17 inches. In Yorkshire, Lancashire, and elsewhere, figures had been taken from time to time in such number that it was possible now to form a very good idea, by reference to the character of the drainage-area and the deduction to be made from the available rainfall during the driest three consecutive years, of the net amount upon which calculations could be based. In 1899 there was a big fight in Parliament over the great central watershed of England, the Peak district of Derbyshire. He had been the engineer for one of the competing schemes, Mr. Hawksley had been the engineer for another, and Mr. J. B. Everard, M. Inst. C.E., the engineer for a third. A joint Board had been formed, and the whole of the extensive drainage-area of the upper Peak districts had been placed in the hands of that Board to carry out works for the benefit of Leicester, Derby, Sheffield, and, to a limited extent, Nottingham. When the Bills were before Parliament, he made a calculation for the quantity of water which he believed would be obtained from his scheme. Without a single rain-gauge on the area, guided only by gauges of which one was his own standard gauge at Sheffield, the next adjoining gathering-ground, and dealing with the question on the lines that he had indicated, he had made out that from that drainage-area 43,638,000 gallons per day were obtainable. The Parliamentary Committee passed the Bill, but, owing to

Mr. Eaton. difference of opinion as to the rainfall, they appointed referees, and the three referees appointed carried out observations on fifty-four rain-gauges spread over an area of 32,000 acres. The observations were carried on for 6 years with every possible care, and in the end an award was made as to the available rainfall, which was given as 45,629,000 gallons per day, or about 2 million gallons per day more than the figure he had himself put before the Parliamentary Committee in 1899, based solely upon the methods of calculation which he had mentioned. If in a total of 45 millions there was an error of less than 2 millions, there was no necessity to take a despondent view of the present methods of obtaining information. Waterworks-engineers, if they only applied it in the right way, had plenty of information to enable them to make their calculations within such a reasonable degree of accuracy as, with properly constructed works and adequate storage, would give results satisfactory to the engineers who designed the works and to the people for whom they were designed. With regard to the remarks made by Mr. Hunter as to the importance of suppressing waste, in 1869 the town of Sheffield was put on constant supply for the first time. Immediately before the introduction of the constant supply the consumption was 21 gallons per head per day, with the water on 12 hours per day. On the introduction of the constant supply it rose instantly to $41\frac{1}{2}$ gallons per head per day. The water-company, being satisfied that that was due to defective fittings, obtained, under the guidance of the late Mr. Hawksley, a code of regulations which they fought out before the Justices with the whole town opposing them. The total expense of getting the regulations was upwards of £11,000, but they were obtained and put into operation, and he entered upon the work at the end of 1869 or the beginning of 1870. The waste was suppressed, and in 3 years the supply had been cut down to 16 gallons per head per day; 5 years later it was down to 15 gallons; and between 1877 and the present time it had oscillated between $14\frac{3}{4}$ and $11\frac{3}{4}$ gallons in 1905 for all purposes other than metered supplies. All water taken for the extinction of fires, the evaporation from open watercourses and exposed surfaces of water in the reservoirs, water used for gardening, and for domestic purposes, with the water on day and night—in fact, everything other than the measured supplies—was included in that figure.

Mr. Lowcock. Mr. S. R. Lowcock remarked that in view of the experience of the action of limestone chippings in filters dealing with upland waters containing vegetable acids, it seemed as if some such result as had actually occurred on the Thirlmere aqueduct might have been anticipated.

He had not read into Mr. Hill's Paper the pessimistic view which Mr. Lowcock. Mr. Eaton seemed to have found. He quite agreed with the Author that the more information they obtained the better engineers would be able to carry out their work, and the less uncertainty they would feel. He did not think that that was gibing at other water-engineers for not making good use of the information within their possession; it was merely asking for more information. The figures given by Mr. Eaton and those in Mr. Tait's Paper went to confirm the view that the more information there was available on this somewhat abstruse and difficult subject, the better for everybody. In three districts close to one another Mr. Eaton had given the loss in the driest three years as 15 inches, 18 inches, and 20 inches; and the arbitrators on the Talla area had estimated the loss to be anticipated at 15 inches. With a recorded range between 15 inches in one place and 20 inches in another close by, it would require good guessing to get anything like an accurate result on some other, possibly distant, watershed, about which no information was obtainable. The fallacy of trying to deduce anything from one rainfall-gauge was shown by Mr. Hill, and also in the Paper on the Talla waterworks, where the average annual rainfall over 7 years for the whole area was 62·51 inches, and the nearest to that average, oddly enough, was the lowest gauge of all, with 61·43 inches. As far as he could see, the increase due to altitude did not in this case apply at all. It was obvious that a great deal more information was required, and the question was, how was it to be obtained, and who was to pay for it? He agreed that it was a national matter, but he did not quite agree with Mr. Hunter that the county councils were the best authorities to take it up, unless several councils were associated, because the area over which each had control was far too small, and they would not agree as to who was to do the gauging and who was to pay for it. It was not to be expected that the people who owned the land, or the authority which controlled it, at the top of the valleys would go to the expense of making observations for the benefit of the people down below; and it was quite certain that the people down below, if they had already a catchment-area of their own, would not feel inclined to pay for what might some day be of value to their neighbours, or to somebody else in another watershed altogether. He quite agreed with Sir Alexander Binnie's suggestion that it would be an excellent thing if in all future Acts the water-authorities were compelled to keep and publish accurate records, both of the rainfall and, as far as possible, of the water flowing off. Mr. Hill suggested that all existing companies or authorities who had waterworks should also keep such records of their own areas,

Mr. Lowcock, and presumably make them available for general use. Mr. Lowcock would like to go a little farther, and suggest that it would be an excellent thing if, in addition to these, there were similar records for the unappropriated areas, which at no distant time would be required for use. The only practicable way would be to hand over the duty of keeping such records to River Boards, to be formed as suggested by the Royal Commission on Sewage-Treatment. Then, of course, each river would have an authority dealing with it from its source down to the sea or to its confluence with a larger river. The rate necessary to pay for this work would be very small when spread over the whole district. Any authority possessing waterworks should pay for the cost of keeping the record so far as its area was concerned, because it would benefit thereby. A community which took up an area at present unappropriated should be called upon to repay to the River Board the cost already incurred of keeping those records, with, of course, interest on that cost, and should continue to keep them, or pay the River Board to do so. In that way it would be possible, he thought, to get a complete set of records which would be of infinite value to every engineer, and to the public in general.

Mr. Thrupp. Mr. E. C. THRUPP remarked that there was one sentence in the early part of Mr. Hill's Paper which might perhaps be the cause of a little misunderstanding. Mr. Hill said that published accounts of thorough and reliable experiments of the yield of collecting-areas simply did not exist. That was rather unfortunately worded. It was known to many that numerous records existed, and perhaps if Mr. Hill had been a little more diligent in hunting for them, he might have found some actually published. Mr. Thrupp had taken a great deal of trouble in the endeavour to find out some relation between the rainfall and the flow off the ground, and he had soon come to the conclusion that it was practically a hopeless problem. Although Mr. Eaton had said that he considered there existed perfect data to enable the required calculations to be made, his only evidence was the gaugings shown in the diagram which he had put on the wall (*Fig. 2*, p. 212). Mr. Eaton had obtained that information by gauging and not by observation of rainfall and evaporation. Evaporation was arrived at by deducting the records of the gauges from the rainfall, and therefore Mr. Eaton received his information in exactly the same way as Mr. Hill wanted it obtained in the future. The only conclusion that could be drawn from studying a large number of gaugings and the flow off the ground was that much more information was required with regard to gaugings, and the main difficulty in the way was expense. It seemed to be

a general view that in order to make actual gaugings of a stream it was absolutely necessary to have a weir. A weir was an excellent thing for gauging water if it was necessary to know the result within, say, 1 per cent., but it was not necessary to go to that extreme degree of accuracy, and if the results could be obtained within 5 per cent. by a much cheaper and less troublesome method of gauging, it would be possible rapidly to collect a much larger amount of information than was available at the present time. He had tried to find a simple way of gauging water in open streams—something that would not involve the construction of weirs or the use of the ordinary current-meters. At first he had aimed at improving the Pitot-tube arrangement, but after some study of that he had come to the conclusion that it was a very difficult thing to elaborate for use in streams, although it was an excellent instrument for studying the flow of water in pipes. In the course of his studies he had come across a statement by an Austrian engineer, Von Wex, to the effect that a small obstruction put in a stream would not produce any ripples until the velocity attained 9 inches per second. Professor C. Vernon Boys had also made some interesting studies of the movement of ripples, and he had shown that ripples could not move on the surface of water without a velocity of about 9 inches per second. With that fact in mind, Mr. Thrupp had been struck with the idea that ripples might be used in some way for measuring the velocities of streams, and he had set to work to study that point. Starting by dipping nails into water, he had arrived at the same results as Professor Boys. If a nail were placed upright in water flowing at a velocity a little exceeding 9 inches per second, ripples were formed as indicated by *Fig. 3*. The angle between the diverging lines of ripples became more acute as the velocity increased. A single nail dipped in that way gave some indication, but it was very difficult to measure the angle of divergence, because the fluctuation in the velocity of the stream disturbed the direction of the ripples, and caused them to move to and fro. He therefore put another nail 6 inches away, which gave two intersecting ripples, and he found that the distance from the base-line to the point of intersection of the last ripple afforded a good means of measuring the actual velocity of the surface of the water. [The speaker exhibited the instrument.] Calling that distance l inches, w inches being the standard dimension of the instrument, he had obtained the following equations for the values of v in feet per second :—

$$\text{For } w = 6, v = 0.40 + 0.206 l.$$

$$,, \quad w = 4, v = 0.40 + 0.28 l.$$

Mr. Thrupp. With a velocity of 0·8 foot per second the distance from the base-line to the point of intersection was about 2 inches, and at $3\frac{1}{2}$ feet per second it was 15 inches. Therefore, with velocities ranging between 0·8 foot and $3\frac{1}{2}$ feet per second there was a range of scale of about 13 inches, which was a very satisfactory length for measuring the velocity. He thought that if Mr. Hill's suggested engineer at £150 a year, instead of wandering about on 10,000 acres of moorland, devoted himself to gauging water in streams, he would collect much more information in the same time, and the results would be much more useful. With regard to the cost of such experiments, Sir Alexander Binnie's suggestion to get at the people who wanted the

Fig. 3.

water, when they applied to Parliament for powers to carry out further works, was excellent; but Mr. Thrupp would suggest that, instead of being asked to procure information, they should be charged a certain sum which should be passed on to a department—perhaps under the Local Government Board—whose duty it would be to see that the gaugings were carried on at those works, and to devote part of the money to collecting information in other districts. The gauging should be carried out at all works, and, if necessary, the Local Government Board should have a right to make an order varying the amount of water which was to be given as compensation if it should turn out that the calculations upon which the scheme was based were not in accordance with subsequent gaugings. The Paper

made a definite suggestion, and he was surprised that in the discussion so far nothing had been said about it. There was a general consensus of opinion that more gaugings were wanted, and he would like to know whether it would be possible to take the opportunity of this discussion to form a Committee of the Institution to approach the Local Government Board and to lay the matter before them. Perhaps, before the meeting ended, some indication might be given by the President as to the possibility of that course.

Mr. CHARLES HAWKSLEY asked how Mr. Thrupp got over the difficulty caused by wind on the surface of the water in connection with the ripples.

Mr. THRUPP replied that there would no doubt be occasions and circumstances in which high winds would disturb operations, but in practice those occasions were rare. The magnitude of the ripples caused by 3-inch wire nails (which were about $\frac{1}{8}$ inch in diameter) was sufficient for ordinary work. For regular gauging a scale of discharges at different depths of water would soon be arrived at, and generally checked by velocity observations; and an occasional omission of the velocity-reading would make no appreciable difference in the result of several years' gaugings.

Mr. ALEXANDER GIBB observed that very little had been said about the actual construction of the Talla reservoir, and he would like to ask the Author whether he had gone into a comparison of a masonry dam with a puddle dam, and could give any figures which would show the approximate cost of the two forms. When puddle had to be brought 32 miles, and cost 10s. per cubic yard, the difference in cost between a masonry dam and a puddle dam might be very small. It was also evident that there was a great deal of stone on the site, not perhaps available for masonry, but quite good enough for making concrete. If a masonry dam had been adopted, he believed the outlet-tunnel could have been saved, or at any rate a certain portion of it; and as the Author said that that had cost £20,000, it would have been a considerable saving, although the ashlar for the facing might have had to be imported, which also would have affected the cost. Perhaps the Author could say, too, why the outlet-tunnel had not been lined simultaneously with the mining. A length of 400 yards of tunnel had been constructed in 9 months, and the whole tunnel appeared to have been left until the end before the brick lining was started. Indications were given that trouble had been encountered owing to the movements of certain parts of the tunnel, and it was quite possible that, had the tunnel been lined at once, that trouble would have been avoided. At all events, in a place where water-tightness was of great

Mr. Gibb. importance it would appear safer to get the ground held up as soon as the excavation was finished. It seemed a pity that no general plan of the works was given, as it was somewhat difficult to follow the intricate details of the Paper without a plan. The position of the outlet-tunnel was left quite vague. The puddle was mentioned as having been put in by means of a cableway 500 yards long, and the average rate of working of that cableway was given as thirty-five journeys per day, which seemed to be slow; it meant that it took 17 minutes to deposit every 2 cubic yards of puddle put in by that means. It would be interesting to have some figures showing the difference in the cost of putting in puddle by that method and putting it in by means of shoots, which were said to be 30 per cent. more rapid. As to the working of cableways of that description, he had recently had some experience at the new Kew Bridge, where a cableway had been used for taking down the whole of the old bridge and bringing forward all the materials used in the new. Although that cableway had been shorter, instead of thirty-five journeys an average of over one hundred journeys per day had been made, and it had been worked up to as many as two hundred journeys per day on certain occasions, which meant 800 tons dealt with, and one return journey every 3 minutes. He did not believe that cableways were very economical if any other form of conveyance could be used, either by a route underneath or by a temporary bridge. Generally speaking, what struck him about the Paper was the low cost of the reservoir for the amount of water impounded, and the rather heavy cost of the aqueduct. The reservoir had cost £250,000 and the aqueduct £750,000, or £23,000 per mile, and perhaps the Author could say why that was so. No doubt part of the expenditure was due to the excellent precautions taken to reduce the cost of maintenance, and the benefit of that would be felt later on; but still, in view of the size of the tunnel, it seemed very heavy.

Mr. Lockhart. MR. WILLIAM S. LOCKHART remarked that Sir Alexander Binnie had given instances of simple and complicated drainage-areas, and he would like to mention one which he thought might fairly be taken as a complicated case, in order to emphasize the great caution that should be exercised, especially by engineers practising abroad, in carrying out work where facts were unobtainable and work had to be based very largely on surmise. Some years ago he was in the Shan tableland of Upper Burma, a typical monsoon country with a rainfall of 150 inches per annum, practically the whole of this rain falling between the last days of May and the first days of November. During this period the country was covered by a pall of thick cloud, the sun being hardly ever visible. The result was

that it was very cool, the temperature generally ranging from Mr. Lockhart. 65° F. minimum at night to 67° maximum only in the day. From the place where he was stationed a cart-road ran down to another station on the Irawadi, about 60 miles distant, where a large amount of machinery had to be landed. At this point, about 450 miles from its mouth, the river was about $\frac{3}{4}$ mile wide, with soft, sloping banks, the range between low river and high river being about 50 feet. Under these conditions it was impossible to build anything in the way of a landing-stage or jetty, and he therefore decided to put down a skidway, as soon as the first rains were over, to drag heavy parts up from the lighters and land them over the floor of a go-down into country carts behind. At each side of the go-down there was to be a store for perishable goods and it was therefore necessary that the floor should be above highest water-level. The height was limited, as the road came down a small spit off which any made work would inevitably be swept by the river when in flood. In the first year the monsoon was abnormally heavy; he considered this a fortunate circumstance and ordered the height of the river to be gauged each day where it was desired to build the go-down, the floor-level being eventually fixed at 2 feet 6 inches above the highest water-mark. The next year the monsoon was abnormally light, but to his surprise, the river rose 2 feet 6 inches above the go-down floor, or 5 feet above the highest level of the previous year. The consequences at that point were trivial, but Mandalay, 80 miles below, narrowly escaped destruction, as the city lay on a sand-flat considerably below the flood-level of the river and was protected only by an earthen bund. The water had risen to the top of this bund and was actually spilling over when, to the relief of everyone, it at last began to fall. The explanation of this state of things was, that during heavy monsoons the sun was not able to penetrate the pall of cloud already referred to, but during this abnormally light monsoon the snow and glaciers on the slopes of the distant Himalayas were exposed to the heat of the tropical midsummer sun and the country was flooded with snow-water in addition to the monsoon rains.

Mr. TAIT, in reply, desired to thank the Institution for the kind Mr. Tait. way in which it had received his Paper, and to join in the appreciation that had been expressed of the other Papers. Some years ago, with the kind assistance of Mr. G. H. Hill and Mr. Barnett, he had had the opportunity of visiting the repair-work at Hutton Roof and had been pleased to see how well-organized the work was. He desired, however, to ask Mr. Barnett the cost of the work carried out. The $1\frac{1}{2}$ million gallons per day lost from the aqueduct was a

Mr. Tait, serious matter, which should be closely inquired into. In the case of the Talla works a good deal of limestone country had to be passed through, and having heard a little of the trouble in the other place he had taken care to avoid the use of limestone concrete. This had made some little difference in the cost of the work, but in view of the difficulty of getting to a place half-way through a tunnel which might be a couple of miles long, and interrupting the flow of water to make repairs, it was worth while going to a reasonable expense to import stone of some other kind—in the case under consideration whinstone—in order to make certain that no trouble would be experienced afterwards. With regard to Dr. Deacon's remarks about the figures on p. 106, it appeared to Mr. Tait that if two deductions, both expressed in inches, were to be made from the average annual rainfall, also in inches, it was quite immaterial which deduction was made first. Having regard to the wording of the Edinburgh Water Act, there seemed no reason why effect should not be given to Mr. Blyth's contention; but supposing that had been done, it would have increased the quantity of compensation-water from nearly 5 million gallons per day to at least $6\frac{1}{2}$ million gallons per day, and would have greatly increased the storage that would have had to be provided. After carefully considering the points raised in the discussion in reference to calculating available rainfall, he was not in the least inclined to turn from the old and well-recognized practice of calculating it upon the driest three consecutive years. If the average rainfall had to be taken as a basis for the compensation-water, then why not take the average for domestic supply also? But that became a very serious matter. In looking into the question before Mr. Blyth and he met Mr. Mansergh, he calculated what the effect would be at Talla if the average rainfall were taken, and he saw that, instead of providing the ordinary 150 or 180 days' storage, it would have been necessary to provide for more than 600 days, and even that figure was not quite as high as the figure given by the late Dr. William Pole in a lecture at the Institution some years ago.¹ Another effect of making the fullest use of the yield of catchment-areas, so that no water should ever run to waste, would be to cause trouble with the

¹ "I have taken some trouble to get a rough notion what size of reservoir we ought to have to equalize the 43 years' rainfall . . . and I find it would require a store of something like 900 days' supply. It is altogether unreasonable and impossible that a waterworks-undertaking could be burdened with such a monstrous construction."—W. Pole on "Water-Supply," p. 43. Lectures on "The Theory and Practice of Hydro-Mechanics," delivered at The Inst. C.E., Session 1884-85.

filters. By-wash channels alongside reservoirs would be of no use to anybody. A by-wash channel was specially made so that water might be selected. If water had to be taken in all states and none sent past except as compensation, it would be necessary to take the "porridge," as it very often was, delivered after very heavy floods; there could be no selection of water, and the cost of filtering the water delivered from a reservoir which took everything it got would be extreme. He was afraid that some of the criticism of the Papers could not have been uttered with due regard to the pockets of the tax-payers. With regard to the position of filters, he agreed with Dr. Deacon to the extent that if there was a built aqueduct the whole way, or a great part of the way, from the reservoir, there might be some saving in placing the filters high up; but if there was not a built aqueduct the whole way from the reservoir to the town, that might be a very expensive plan. The filters worked evenly over the 24 hours, while the water which was required in the town was only drawn over a period of about 10 hours. If there was no built aqueduct, it might be found that the cost of the main between the filters and the town was very heavy. So far as the Talla drainage-area was concerned, there would be some trouble in making filters, as the ground generally was like the side of a house. To filter 10 million gallons per day would require a tolerably flat area of several acres, and there was no place at anything like the necessary level for forming the filters. They might be built by using heavy retaining-walls and going in for a great deal of rock-cutting, as had had to be done with the filters at Rhayader, but the cost would be absolutely out of reason. Fig. 1, Plate 3, showed that Edinburgh drew supplies from a number of sources, and if the filters in connection with each of those sources were placed close to the source, what would happen if assistance was required when one set of reservoirs was drawn down low, and there was plenty of water to spare in the other reservoirs? In the past, by making use of filters close to Edinburgh, water from several different sources had been filtered there. This certainly could not have been done if the filters had always been close to the reservoirs. Then it must be borne in mind that as some aqueducts lost a little water, the money spent on the filtration of the quantity leaking would be thrown away. Some other aqueducts intercepted water at different places along the line, which would not be treated at all if filters were placed at the reservoir. The first length of cast-iron siphon next to Talla reservoir had been carefully examined after being in constant use for a year, and the deposit in it was barely perceptible. He would have been glad if the discussion

Mr. Tait. upon filters had been carried further, in order that a definite pronouncement might have been made on a question which presently occupied the attention of many local authorities, namely, the relative efficiency and cost of sand and mechanical filters. Dr. Deacon's reference to the use of limestone in sand filters raised a very interesting question of which a good deal would likely be heard in the future.¹ The valuable observations upon rainfall and discharge contributed by Sir Alexander Binnie and Mr. Hawksley showed very clearly how much a stream was bettered by the regular discharge of a reasonable quantity of compensation-water from a reservoir. He had to acknowledge his indebtedness to his eminent predecessor Mr. James Leslie, who, during an official career of nearly 50 years, had collected (with the assistance of a large number of reservoir-keepers whom he had initiated in the habit of making careful observations) a vast amount of data regarding rainfall, evaporation, floods, etc. While a good deal of the available matter remained to be published, Mr. Tait was glad to say that the observations were still being carried on. One of the first things that Mr. Blyth and he had decided upon in considering their award was that they would publish their figures. In handing in their award they took the opportunity of recommending the Water Trustees to continue the reading of the rain-gauges in the Talla drainage-area, and it was a great pleasure to them to find that this suggestion was adopted. It was to be hoped that many other local authorities might follow the example thus set. With great deference to Mr. Ernest Hill, Mr. Tait believed that, with the aid of reasonably accurate tables of contents, the gauging of the discharge could be very satisfactorily performed by observations of the movement of the water-level in the reservoir when constructed (provided due account was taken of the water drawn off or lost by evaporation). It was his experience that weirs were troublesome things to deal with in wintry weather after ice had formed on the whole or some portion of the crest. The Talla water when first available had been very urgently required in the compulsory area of supply, and there had been no opportunity of scouring off large quantities of water. Since the filling and testing of the reservoir considerable quantities of water had been run off, with the result that the water-level had been drawn down more than 12 feet. This had given an opportunity of repeating a portion of *Fig. 3*, and

¹ See the Thirtieth Annual Report of the Local Government Board, 1900-01 ; Supplement in continuation of the Report of the Medical Officer, on Lead-Poisoning and Water-Supplies. London, 1903.

careful observations were being taken during the refilling of the top Mr. Tait. 12 feet of the reservoir with a view to comparison with the corresponding portion of the diagram. Keeping in view that the water in a reservoir was never at its best on the occasion of the first filling, there seemed little reason why similar observations should not be frequently made with all new reservoirs having a capacity of at least 1,000 million gallons. He agreed with Sir Alexander Binnie that Parliament might quite reasonably put certain obligations upon authorities and water-companies to keep accurate scientific records. He could not help feeling, however, that something might be done by the Institution in the way of lending recording instruments. It was much more likely that there would be water to spare for experimental purposes for the first 2 or 3 years following the construction of a reservoir than for many years to come thereafter. Local authorities would be chary about buying instruments which they would only use for a year or two; while for all the capital cost involved the Institution might be the means of obtaining some very useful information indeed. Having been associated with Mr. Blyth in the Wishaw Water Opposition, Mr. Tait quite agreed that, as a result of the decision upon that and other more recent Bills, no Scottish engineer could reasonably expect to get off with compensation fixed at less than one-third of the available water, if his Bill was contested. There had no doubt been cases where compensation was given only upon the quantity of water actually operated upon, but provision was usually made in such cases for a sliding scale commencing with a well-defined minimum quantity. In the Wishaw Act there was not only a definite minimum but the total amount of abstraction was limited. This was only natural, having regard to the very enterprising scheme originally presented to Parliament, which, if it had gone through unopposed, would have handed over to the promoters the control of the whole of the water yielded by a catchment-area of 9 to 10 square miles in a fairly wet district. Several of the Edinburgh and District reservoirs were entirely for compensation purposes, and the control of the discharge of the water from these reservoirs was vested in committees of landowners, millowners, etc. Lord Home was practically the only petitioner upon the question of compensation-water when the Wishaw Bill was before the House of Commons, but the "fiery cross" was out before the Bill reached the House of Lords, with the result that practically every landowner for many miles down the stream petitioned against it, and it was then that what was now a ruling decision as to compensation-water was given. With regard to the point which Dr. Mill had raised as to the placing

Mr. Tait. of the gauges on the drainage-area Mr. Tait might say that the sites had been chosen by his predecessor and Mr. Blyth with a view to give truly representative information as to the rainfall on the area, having regard to the fact that only as many gauges should be placed as could be read by observers on one and the same day. It seemed probable that some very useful information would have been obtained had twice the number of gauges been installed, but it was open to question whether the expense would have been justified. He was glad to find that, although Dr. Mill had gone into the whole matter of available rainfall at Talla quite independently, he had not brought out a result differing greatly from that which had been adopted. Mr. Tait did not quite agree, however, with Messrs Blyth, Mill, and Hill's proposed Government intervention. He believed much more in results brought out by private and municipal enterprise, controlled, perhaps, by somewhat more stringent protective clauses than at present; but he did not think the Institution should let the matter drop without framing some model clauses for further Acts. With a Government authority as had been suggested, Wishaw might never have gone to Elvanfoot; but he did not think any ordinary person would object to the Wishaw scheme as finally modified before receiving the Royal Assent. He quite agreed with Mr. Hawksley's suggestion that it seldom paid to impound the whole of the average rainfall, but he went further, because he believed that better water resulted in many cases when provision was made for sending past a good deal of flood-water, and for selecting the water actually used for domestic purposes. In reply to Mr. Hawksley's question, the cost of the reservoir stated on p. 112 did not include the cost of the railway. The railway, being side by side with the aqueduct (though at a lower level), had been made use of to a very considerable extent in the construction of the aqueduct; and no doubt it would be of further use in the construction of additional reservoirs when the adjoining water-sheds had to be tapped. In answer to Mr. Balfour, Mr. Tait believed that if it had been known at the very outset that the embankment would take so long to construct (about 7 years) the front slope might not unreasonably have been slightly steeper, but he had calculated that the steepening of the slope to 3 to 1 would have saved a comparatively small sum. The early consolidation of the embankment had been assured by the use of horses and carts without planks or rails, and also by following the well-known practice of carrying up the embankment in layers 12 to 18 inches deep. These were matters which had been discussed on previous

occasions in the Institution, particularly by Mr. Thomas Hawksley¹ Mr. Tait, and by Mr. Robert C. Reid.² Mr. Balfour's question as to the actual amount of settlement could only be answered 30 or 40 years hence, but it was Mr. Tait's experience that a similarly formed embankment settled to the extent of about 9 inches or 1 foot during a period of 20 to 30 years following upon its construction, provided the total height was not more than about 50 feet. Provision had been made for settlement at Talla. He desired to congratulate Mr. Hunter on the success which had followed his efforts in the tracing and reduction of waste. Mr. Tait also had some satisfactory results to show, notwithstanding the special obstacles in a place like the Edinburgh and District compulsory area, which varied in height from 500 feet above Ordnance datum to sea-level. The 36-inch valves had been made entirely of gun-metal in view of an unfortunate experience which the Trustees had had with ordinary valves at another reservoir which stored equally soft water. So far the greatest depth of water which had run over the waste-weir was 12 inches, but he confidently expected that on some occasion of heavy rainfall and rapidly melting snow this depth would be considerably exceeded. In instituting a comparison between the cost of a masonry and an earthwork dam, Mr. Gibb had raised a very interesting question. It was quite clear that even with the assistance of the railway to bring in proper stone for facework, the cost of a concrete dam at Talla would have exceeded to some extent the cost of the earth dam constructed. There might perhaps have been a little saving in the time occupied in construction, but then account must be taken of the fact that the reservoir could not have been used for supply until the completion of the whole aqueduct. Mr. Tait agreed that a general plan of the reservoir would have helped members to follow the arrangement of the works more easily, but the plan he had sent in could be referred to at the Institution. As to the question whether or not the lining of the outlet-tunnel should have been carried on close behind the face as driving proceeded, he believed, after taking all the circumstances into account, that the proper course had been followed. In his Paper he had drawn special attention to the water which got away from the shafts. This water would still have got away if the lining had proceeded at the same time as the driving, because no one had any reason then to suspect that the rock several feet away from the extrados of the tunnel had been shattered by the use of the higher explosives. The cost of the

¹ Minutes of Proceedings Inst. C.E., vol. *xxi*, p. 70.

² *Ibid.*, vol. *xxxiv*, p. 94.

Mr. Tait. aqueduct did not seem very high when regard was had to the size of the tunnel, the available fall, the ground to be passed through, and to the fact that the tunnels and cut and cover had been made large enough in the first instance to bring in ultimately water from additional watersheds.

Mr. Barnett. Mr. BARNETT, in reply to Dr. Deacon, pointed out that Table VI (p. 180) showed the relative effect of the soft water on each of the experimental blocks of limestone whose chemical composition was given in Table II. From a comparison of these Tables it would be seen that the effect of the water was least serious on experimental blocks X and XX, which contained the least proportion of calcium carbonate (CaCO_3) and the highest percentage of insoluble siliceous matter. No doubt had all the fine grit and dust been screened out of the broken limestone, and only a good siliceous sand used for the mortar, the action of the water on the limestone would, as Mr. Hawksley had suggested, have been less rapid; but the mischief would not have been prevented. The method described by Mr. Balfour of getting a definite thickness of cement-mortar facing on a concrete culvert, would be a suitable and cheap way of constructing a new culvert, where the conditions met with were similar to those at Hutton Roof. He had not attempted in the present Paper to deal with the question of the best form of culvert to use in any particular circumstances. This might be more suitably treated in a Paper dealing generally with the subject of waterworks-tunnels; and he intended to write such a Paper, putting on record the results of his 20 years' experience in the construction of such tunnels. He regretted that he was unable to give the information asked for by Mr. Tait as to the cost of the repairs. All the materials, plant, etc., had been ordered, and all payments made, direct from Manchester, and on making inquiry as to the details of the cost up to the time when the work was suspended, he had found that the expenditure on the work at the Hutton Roof repairs had not been kept sufficiently separate from that on work carried out simultaneously at other parts of the aqueduct to allow of a reliable statement of the cost of Hutton Roof section being given. As mentioned in the Paper, the work done at Hutton Roof had effectually stopped the loss of water on that section, so that any shortage there might still be at the Manchester end was due to a cause or causes beyond the scope of his Paper.

Mr. Hill. Mr. HILL, in responding, observed that he was glad to have been the means of eliciting such an interesting discussion upon the collection of further particulars with regard to rainfall and flow off the ground. Mr. Hunter had asked for the names of places which

had had to buy back a portion of the compensation-water where too Mr. Hill. large a quantity had been given. Manchester in 1848 gave 75 cubic feet per second for 12 hours of each working-day, and in 1854 purchased back 20 cubic feet of this quantity. Dewsbury gave 15·19 inches of rainfall on its old works, and only 9 inches later on for its newer works adjoining. There were other cases, but some time would be required to turn up the records of so long ago. Mr. Hunter had also mentioned laying pipes along railways. An Act of Parliament was obtained for the extension of the Thirlmere aqueduct 2 years ago, and 5 miles of the pipes were arranged—as was thought, very properly—alongside the railway, but not on railway ground. The railway-company were horrified at the idea, and put the corporation under all sorts of special restrictions, such as automatic stop-valves, steel pipes, etc. He did not know how it was that Mr. Eaton had gained such an unfortunate impression that the Paper was pessimistic; it was intended to be anything but that. It might have been because some of Mr. Hill's views on the subject had been expressed in the discussion on Mr. E. Sandeman's Paper on the Plymouth water-works,¹ and he had avoided covering the same ground again in the present Paper. Those remarks he had put together very carefully, and he did not wish to go over them again. He thought that Mr. Eaton's contribution to the present discussion showed as forcibly as anything the necessity of having further observations. What was so well done in the case of Sheffield might be done in other places. Sheffield and Doncaster covered a very small area, and it was not possible to do as Mr. Eaton would do—take the experiments and apply them all over the country by means of Mr. Hawksley's ingenious formula. He would like to ask Mr. Eaton if any of the results of the experiments to which he had referred had been published. He believed they had not. They were within his own knowledge, because Mr. Eaton had very kindly given them to him in previous years; but what was given to him he would like to be available for the other members of the Institution. He did not say in his Paper that there was no information: that would have been an impertinent remark to make in view of the number of distinguished waterworks-engineers who had joined in the discussion, and it would not have been true. But the information was nothing like as complete as it ought to be, and was rather casual and haphazard. He did not doubt that all waterworks-engineers possessed some experimental data, and he thought the only reason why they had not been published was that it was felt they

¹ Minutes of Proceedings Inst. C.E., vol. cxlvi, p. 20.

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