Discussion.

Prof. Dixon. Professor DIXON exhibited several lantern-slides showing the model installation at the Nant-y-Gro dam.

Dr. Unwin. Dr. W. C. UNWIN, Past-President, remarked that the Paper was so complete that it did not lend itself to very much discussion. It described one of those admirable pieces of experimental work by which what was known about hydraulics had been built up. He did not think it would have been possible, without carrying out the experiments described, to determine satisfactorily a coefficient to use in making a calculation of the discharge over the Caban dam. The following Table provided an interesting comparison of the Authors' coefficients with Bazin's coefficients for the standard sharp-edged weir with the end contractions suppressed and the weir so high that the velocity of approach was practically negligible.

Values of C in the equation $Q = CLH^{1 \cdot 5}$.

H . . . . Feet	0·525	1·05	1·50	1·97
Bazin C	3·43	3·42	3·44	3·48
Dixon and Macaulay C . .	3·08	3·04	3·02	3·01
Theoretical C.		3·09		

The difference was large, as one weir was sharp and the other broad-crested. The theory for a broad-crested weir was different from that for a sharp-edged weir; he had published such a theory 40, and again 20 years ago, but he did not claim that it was his. That theory gave the value of the coefficient of discharge independently of experiment. It was a semi-rational theory, depending on an assumption, not exactly proved, but not unreasonable. The coefficient for a broad-crested weir given by that theory was 3·09 — nearly identical with the figure at which the Authors had arrived. It was too much to expect a water company to go beyond the problem which they wished to solve, in order to help hydraulicians; but it did strike him that it would have been of value to engineers if the Authors had gone just a step further. Wing walls were fitted to the upstream edge of the dam, and, if a floor had been put in at various distances below the crest of the weir, the Authors would have obtained values of the discharge when the velocity of approach was taken into account. That would have been a useful expansion of the work described, and it would not have cost very much. The experiments had been carried out in a very satisfactory way and, as shown by the logarithmic plotting, they were no doubt extremely accurate.

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Professor F. C. LEA was particularly interested in the experiments, because, by the kindness of the Authors, he had been able to help them to take certain observations. It was important to recognize that the work described not only gave results such as were published in the Paper, but also helped to determine the discharge-factor for a great gathering-ground; and the Authors must be able, with the aid of those experiments and other data, to give information which would be of the greatest importance. He complimented them upon the apparatus they had designed. The fact that they had been able to get the authority of the City of Birmingham Water Committee to construct such a large measuring-tank was an important factor in the experiments. The tests, even at high heads, had lasted for several minutes. A point of criticism in connection with the method of measuring the heads was that, although the measuring-apparatus could be read to 0·001 inch, it was fairly obvious that small errors of several thousandths of an inch would probably not affect the results very much, and it was difficult in windy conditions to be quite sure of measuring water with anything like that accuracy; in fact, it was difficult in the laboratory. He did not think the Authors would claim that the results were accurate to that extent. It was significant that hook gauges had been used with fairly large apparatus to avoid lag of the readings when surgings took place owing to wind. The results obtained were of considerable interest. The index was not quite 1·5, and, as Dr. Unwin said, the figure of the constant agreed very nearly with the theoretical value for broad-crested weirs. If the viscosity term were determined, when recording such experiments, which in this case had not been possible, he thought perhaps it would be possible to keep the index constant at 1·5. A few years ago he had constructed a sharp-edged weir across a stream in series with a dam similar to that dealt with in the Paper. The index for the dam changed with the dimensions and the width of the weir but kept to the order of 1·5. With regard to the effect of wind, it was difficult to be quite sure of reading the head with considerable accuracy in the open air. In his own experiments much time had been spent on that matter, and it had been found that reversal of the direction of the wind introduced an error, of generally 1 to 3 per cent., but greater in certain circumstances, and tended to introduce variations greater than those due to viscosity. In the Authors' experiments the wind, no doubt, influenced the results. There was little difference in the readings on the three hook gauges: sometimes the nearest gauge had a higher head than the one more remote, but that could hardly be so without some Prof. Lea.

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Prof. Lea. disturbing influence either external to or within the apparatus. The Paper would help in giving knowledge as to the discharge from other gathering-grounds, and the volume of water that might be depended upon to reach the reservoirs. He hoped that advantage would be taken of the site to make other experiments. If other models could be constructed, he was sure they would add considerably to the general knowledge of an important subject.

Mr. Tickell. Mr. R. E. TICKELL remarked that, having constructed the temporary dam at Nant-y-Gro for the village water-supply, where the experiments were carried out, he was particularly interested in the Paper. While in that district, he had attempted to determine the discharges from the watersheds and measure the floods through the culverts. The existing data were very imperfect, and engineers would be only too glad to have a guide such as the Authors had provided. It struck him that the Paper stopped short of the interesting point: a formula was given, but no results; and he hoped that some day the Authors would publish the discharge figures of the drainage-area and the flow over the Caban dam. The weir of the Caban dam was 5 feet broad and was of dressed masonry. The upstream side of the weir had a batter of 1 in 20 and a bullnose of 6 inches radius. On the downstream side was another bullnose, a drop of 6 inches, and then the rock face commenced with a curve of 12 feet radius. A peculiar result was given in experiment No. 13 (p. 109); in every instance the water-level farthest from the dam was lower than the level nearer to the dam. That seemed to indicate that there was a sort of wave of the rising water flowing over the crest. The Authors stated that that would appear occasionally in some of the experiments, but in the experiments given he did not think there was an exception. Another interesting comparison that might have been made by the Authors was with the sharp-edged weir. He had compared the discharges given in Table II with that of a sharp-edged weir, and he noticed that for a head of 1 inch the flow over the Caban dam was only 4 per cent. less than it would have been over a sharp-edged weir. When there was a depth of 5 inches, it was 6 per cent. less; at 1 foot it was 8 per cent.; and at 1 foot 4 inches depth of water it was 9 per cent. less than it would be for a sharp-edged weir. According to text-books, if there was a horizontal surface behind the edge of the weir, with a head of only 1 inch the flow would be 50 per cent. less than that over a sharp edge. The high discharge obtained by the Authors seemed to be undoubtedly due to the bullnosing at the upstream side of the weir. The percentage increased with the greater depth of head, which was opposite to what theory would

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predict, if no bullnose were present. It should be noted that the formula in Table III, which gave the coefficient for the discharge over a rock-faced dam 3 feet long, gave the discharge per linear foot. He hoped that Mr. Macaulay would compare the discharges from the watershed over a long period of years with some of the floods. The comparison of discharges in floods and in droughts would be very interesting. Sir Alexander Binnie cited[1] instances of floods in England of 250, 400, 500, 600, and even 1,000 cusecs per 1,000 acres. He himself had seen a good many floods. The biggest he saw at Pen-y-Gareg during 10 years gave a discharge of 3,800 cusecs from a watershed of 16,000 acres, and the minimum flow of which he could find any record during the time he was there was 1·34 cusec, off a watershed of 16,000 acres. Mr. Tickell.

Mr. E. S. LINDLEY remarked that, while it would seem that practical application of the broad-crested weir was new in England, in the Punjab it had been brought into considerable use on irrigation systems. Its principal applications were: as irrigation-outlets, especially at the tails of channels, to deliver supplies that would be unaffected by the farmers' silt-clearance; for furcations of channels where manual regulation could be avoided, to give proportioned supplies independent of the different and varying water-levels in offtakes; and for canal falls, to make meters of them. In these applications it must be distinguished from the Venturi flume used in America, in which the discharge passing was deduced from gauges upstream and at the throat, as in the Venturi meter; to emphasize the distinction it was called the standing-wave flume, because it was not intended to be used with less than the minimum fall necessary to give "critical" flow at the throat ($v^2 = g \times d$ of standing-wave theory) with a standing wave below it, when discharge was a function of upstream depth only. One of the advantages of this weir, as compared with the sharp-crested weirs usually employed for measurement, was that its discharges were not dependent on cleanness of upstream face and sharpness of crest, which could only be kept constant under laboratory conditions. To avoid this disadvantage, Mr. Clemens Herschel[2] made a suggestion, which later developed into the Herschel weir, involving the giving to the weir-crest of a certain standard roundness; it was probably better to go farther and suppress any contraction of the underside of the nappe completely, leaving only the surface contraction, which Nature would standardize. Another advantage Mr. Lindley.

[1] "Rainfall, Reservoirs and Water Supply." London, 1913.

[2] Transactions Amer. Soc. C. E. vol. lxxxiii (1920), p. 158.

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Mr Lindley. of this weir was that, unlike other weirs, it did not need a complete free fall with admission of air under the nappe to give its standard and maximum discharge. From the reasoning that yielded the rational formula generally ascribed to Dr. Unwin, but just disclaimed by him, it was clear that a drop of water-surface of $\frac{1}{3}H$ was sufficient; actually this could be reduced to $\frac{1}{6}H$ in practice, by adding a downstream glacis on which kinetic energy of flow was recovered. That form of weir could therefore be employed where sufficient head for a free fall was not available; or it could be made much deeper and shorter than a free-fall weir. From remarks made by some previous speakers, there appeared to be danger that the formula derived in the Paper might be set up as the practical general formula for the broad-crested weir, fixing the inevitable difference between theory and practice; that course would be quite erroneous and could not be checked too soon. Essential conditions for flow to conform to broad-crest theory were the following: there must be no contraction by the underside of the nappe leaving the crest; the downstream edge of the crest, at which atmospheric pressure was admitted under the nappe, must be far enough from the " controlling section " to avoid lowering pressures in the fluid below those due to depth below the surface there; flow at the " controlling section " must not depart sensibly from the normal to the section; flow at the " controlling section " must be sensibly on straight lines, as curvature involved departure from the pressures due to depth below surface. Actual weirs might depart from each of these conditions to an infinite number of degrees, and each had its own peculiar discharge-formula. The endeavour in the Punjab had been to find the conditions that the form of the weir must satisfy, to make discharges fit the Unwin formula. In the course of considering why the discharges of many actual works exceeded those of the Unwin formula by more than was *prima facie* to be expected, Mr. E. S. Crump, of the Punjab Irrigation Department, had worked out a rational formula[1] for what might be

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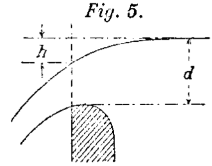
[1] Consider flow past a vertical section through the downstream edge of the crest. At both surface and crest, pressure is atmospheric, so velocity

at surface $v_s = \sqrt{2gh}$ . . . . (1)

at crest $v_c = \sqrt{2gd}$ . . . . (2)

Fig. 5.



Between these points the pressure, and so the head converted into velocity, is unknown. A possible distribution of pressures and velocities that is likely to be not far from the truth, is that of the free vortex, in which velocity is inversely proportional to the distance from the vortex-centre.

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described as a "narrow-crested weir"; this differed from the "sharp-crested weir" in avoiding any contraction on the under side of the nappe, and from the "broad-crested weir" in obtaining maximum discharge by admitting atmospheric pressure under the nappe at the "controlling section." This showed a maximum possible coefficient of 4·184, as compared with the value 3·09 for a broad crest with rounded entrance, and 2·64 the minimum for a broad crest with sharp entrance.[1] This coefficient 4·184 was higher than had been realized in any known or published experiments in which it might be looked for. Certain of Bazin's experiments[2] on a weir of triangular section with 1-to-1 slopes upstream and downstream, showed coefficients up to 4·27, in spite of the contraction Mr. Lindley.

For the sake of a trial solution assume this and, as usual, ignore the fact that velocities are not all normal to the section under consideration.

Let y_1 be the depth of the vortex-centre below crest-level;

then $v_s : v_c :: y_1 : (y_1 + d - h)$, so $v_c/v_s = 1 + (d - h)/y_1$,

but $v_c/v_s = \sqrt{d/h}$ by equations (1) and (2).

Equating, transferring 1 to the other side, and dividing by $(\sqrt{d} - \sqrt{h})$

$$y_1 = \sqrt{h} \times (\sqrt{d} + \sqrt{h}).$$

At any point at height y above the vortex-centre,

$$v = v_c \times y_1/y = \sqrt{2gdh} \times (\sqrt{d} + \sqrt{h})/y.$$

So the total discharge in unit width

$$D = \sqrt{2gdh} \times (\sqrt{d} + \sqrt{h}) \times \int_{y_1}^{y_1 + d - h} 1/y \, dy$$

$$= \sqrt{2gdh} \times (\sqrt{d} + \sqrt{h}) \times \log_e\left(1 + \frac{d - h}{y_1}\right)$$

$= \sqrt{2gdh} \times (\sqrt{d} + \sqrt{h}) \times \log_e\sqrt{d/h}$ by the second set of equations, or, putting $h/d = f$,

$$= \sqrt{2g} \times d^{1 \cdot 5} \times \sqrt{f} \times (1 + \sqrt{f}) \times \log_e\sqrt{1/f}.$$

Differentiating with respect to f, and equating to zero

$$\log_e f = \frac{1 + \sqrt{f}}{1 + 2\sqrt{f}}.$$

So the discharge is a maximum when $h/d = 0 \cdot 22$

$$y_1/d = 0 \cdot 685$$

and then $D = 4 \cdot 184 \times d^{1 \cdot 5}$.

E. S. L.

[1] U.S. Geological Survey, Irrigation Paper No. 200, p. 120.

[2] *Ibid*, p. 82.

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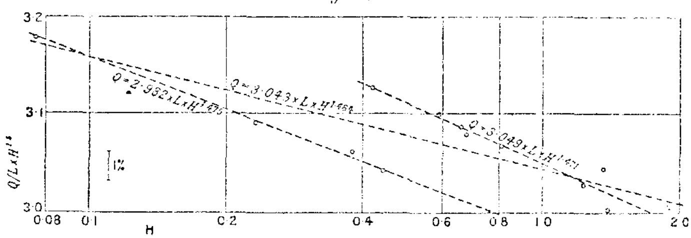
Mr Lindley. under the nappe, indicating that the steep downstream glacis resulted in pressure less than atmospheric under the nappe at the "controlling section." Mr. Lindley had tried therefore to realize this coefficient practically, for the sake of testing the assumptions on which it was based. It would be seen that theory made the flow in effect part of a vortex about a horizontal axis at depth $0{\cdot}685 \times d$ below the crest. The weir tested had vertical upstream and downstream faces with the crest rounded to a plain radius, and air was admitted under the nappe. The experiments were incomplete, but so far the coefficients found rose to maximum values of only 3·88, or 0·93 of the theoretical. As the result of experiments on a small scale, Mr. Crump stated that, if a weir were made with a certain breadth of level crest, preceded by a rounding of no less radius, it would discharge according to the Unwin formula as long as $(d + h_a)$ did not exceed one-half the said breadth, and as long as the drop of water-surface from upstream to downstream was not less

Fig. 6.



than $\frac{1}{3}$ $(d + h_a)$, even when no downstream glacis was provided. This had been confirmed by observation on actual works with up to 40 cusecs per linear foot of discharge ($5\frac{3}{4}$ feet depth), and down to a 1-foot depth for a 10-feet-broad crest. Coming now to the matter of the Paper itself, he suggested that the plotting of the data in *Fig. 4* was not adequate to justify the claim made for consistency in the observations. What he suggested as a more adequate method was shown in *Fig. 6*, the essence of which was plotting against one of the variables (H in this case) the "constant" obtained by applying to the observed data an approximate formula ($Q/(L \times H^{1{\cdot}5})$ in this case). The variation of this "constant" on even a very open scale kept within a diagram of reasonable size. The method was applicable whether logarithmic or ordinary linear scales were the more suitable: in this case logarithmic scales were used, and the diagram showed the very visible interval corresponding to a 1-per-cent. difference, and the very visible change of inclination corresponding to a very small difference of exponent. This plotting

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showed the experimental data lying, not on the one line corresponding to the formula given in the Paper, but quite clearly on two distinct lines that applied respectively above and below $H = 0{\cdot}4$; the interval between the two lines was 2·6 per cent., or appreciably more than should be accounted for by errors of observation with the methods employed. The information given in the Paper was insufficient to enable him to suggest reasons for this. Those who would read this Paper with interest included many who had not access to full sets of the Proceedings. He would therefore ask that full details of the crest of the weir be given for their benefit.[1] He would also inquire how the Authors determined the zero of heads, that was, the mean crest-level of the weir. He believed the crest was fine hammer-dressed with chiselled drafts. The roughness of that would be very appreciable relative to the smallest heads (down to 0·076 foot) dealt with. Where a crest was narrow the mean level might be simple to determine; but where it was broad that was far from simple, as departures from the mean differed in their effect with their distance from the face: near the face they might not matter at all, because the nappe jumped them; near the "controlling section," whose position depended on the head, they were important; nearer the downstream edge they probably mattered no more than the degree of rugosity they represented. Altogether, it was desirable to have details to show that the data observed would apply even to a weir modelled from another 3-feet length of the crest of the same dam. Mr. Lindley.

Mr. M. K. Rice-Oxley considered that the actual execution of the experiments had been as perfect as was possible, but he differed from the Authors on the interpretation of the results. From his own observations of discharges over broad-crested weirs he had come to the conclusion—which the Authors' experiments seemed to confirm—that it was not possible to treat a broad-crested weir in the same way as a narrow-crested weir. The coefficient of discharge depended on two factors: first, the natural features of the weir, which for any one weir depended on the shape of the crest, the upstream and downstream slopes of the walls, etc.; and, secondly, the frictional resistance to the water passing over the surface of a flat broad crest and against the sides of the weir. In the Authors' weir the length was 3 feet and the maximum depth of water about $1\frac{1}{2}$ foot, and it was possible to calculate for any head the pressure of the water against the sides of the weir and the pressure on the Mr. Rice-Oxley.

[1] This has been done: see p. 123, *post.*—Sec. Inst. C.E.

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Mr. Rice Oxley.

flat surface. In such a short weir the pressure against the sides of the weir would be comparatively large as compared with the pressure on the flat surface of the weir. As the length of the weir increased, the relative value of the pressure at the sides of the weir gradually diminished. The Authors gave in Table III the value of C varying with the head for different depths of water "for the discharge over a rock-faced dam, 3 feet long"; and perhaps they had in mind that the value possibly could not be applied for the whole length of a long weir like the Caban weir, which exceeded 500 feet in length. He thought the value obtained for C was correct for a short weir, but it would be too low for a long weir. The coefficient C should be divided into two parts, one due to the physical features of the weir, and the other proportional to the total water pressure on the surfaces over or against which the water flowed per unit length of weir. The friction due to this pressure reduced the velocity caused by the head. The formula might be divided up in the following manner:—$Q = CLH^{1 \cdot 5} = LH \times CH^{0 \cdot 5}$, where LH represented the cross-sectional area of the water and $CH^{0 \cdot 5}$ the mean velocity, the value of H in the quantity $CH^{0 \cdot 5}$ being reduced by an amount proportional to the total water-pressure per unit length of weir. His formula would, therefore, be of the form $Q = LHC\,(H - \mu P)^{0 \cdot 5}$, where C and μ were constants unaffected by the head and P was the total water-pressure on the crest and sides, divided by the length of weir. He had done this with the figures given in the experiments and had obtained two values which were constant for the range of head and any one weir. An examination of those figures showed, he thought, that in most cases his method would give results agreeing to the third place of decimals with the Authors' experimental figures. He ventured to think that the discharge for any head exceeding about 1 inch, over a length of weir such as the Caban, would be under-estimated, if the Authors' equation were applied to it, simply on account of the frictional resistance. A proof of that could be found in the case of regulators in irrigation work which were similar as regarded friction to the weir with which the Authors experimented. In that case the value of C rose very rapidly with the width of the weir, because the effect of the frictional resistance at the sides was less evident on a longer length of crest. He thought that in the case of the Caban weir the value of C in his form of the equation for discharge was about 3·177. The importance of obtaining an exact value for any coefficient of discharge when dealing with a long weir would be realized when it was noticed that, using the Authors' figures and formula, a difference of unity

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in the second decimal place with a head of 1 foot would mean a difference of more than 300,000 gallons a day in the discharge. Mr. Rice-Oxley.

Mr. D. HALTON THOMSON considered the experiments to be valuable, not only on account of their large scale and the positive means employed to measure the discharge, but also because they afforded one more proof, if proof were needed, that it was difficult to forecast accurately the discharge of weirs of irregular section from experiments on other weirs of a similar character, but not of identical section. For instance, unless the tests under discussion had been made, it might have been expected from the published work of careful observers, such as Bazin and others, that the coefficient of discharge C in the standard formula would increase as the head increased, whereas, as seen from Table III, its value steadily decreased with increasing head. The possible explanation might lie partly in the friction of the rough rock-faced radial section beyond the horizontal crest, and partly in that of the sides, as suggested by Mr. Rice-Oxley. Were the Authors satisfied that the timber wings used to suppress the end-contractions had been carried down far enough below the level of the crest? *Fig. 1* appeared to show that they had been carried down less than 18 inches below the crest, as compared with the maximum head of the experiments of 16 inches. Owing to the drawdown of the water as it approached the crest, the water behind the wings would stand at a materially higher level near the crest than the water between the wings. Would not that difference of level, more particularly at the higher heads, induce side-currents under the wings and so in some degree affect the sought-for relation between the head and the discharge? He expressed the hope that the tests might be repeated on small-scale models, because it was apparent from recent Papers read before The Institution that the use of models was likely to prove extremely valuable in solving hydraulic problems. Any chance of actual comparison between full-scale and model experiments which could confirm the reliability of models should not be lost. Usually the cost of the full-scale experiments prevented such comparisons, but since in the present case the major portion of the cost had been already incurred, he hoped that his plea would not fall on deaf ears. Mr. Thomson.

Professor C. BATHO said the Authors had rendered considerable service to all workers in hydraulics by their careful carrying out of the experiments and by building a large-scale hydraulic laboratory; and he hoped it would be possible to maintain that laboratory and make it available for other workers. Possibly some members of the Civil Engineering Department of the University of Birmingham might be able to carry out work there at some time in the future? Prof. Batho.

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Prof. Batho. With regard to the experiments described in the Paper, he considered that they could scarcely be called full-scale experiments, since the length of the crest of the weir was only 3 feet, and that the timber walls must have a considerable effect on the flow. Would it not be valuable to extend the experiments by making another series of experiments with different distances between the timber wings? Possibly curves could be plotted from a series of observations of that kind, and the effect of the wing-walls so determined. Professor Lea had referred to viscosity. A research student at Birmingham, Mr. Hasan Zaky, was at present carrying out experiments with the University experimental channels on the Bournbrook—not a very clean stream—and he had found that the viscosity of the water varied very considerably at different times. The extreme change in the kinematic viscosity was about 55 per cent. By plotting the results of his experiments in the manner adopted by Messrs. Stanton and Pannell, in their experiments on pipes, Mr. Zaky had arrived at the formula

$$\frac{1}{C^2} = \frac{mi}{v^2} = 0 \cdot 0029 \left(\frac{\nu}{vm}\right)^{0 \cdot 403} + 0 \cdot 000052.$$

The kinematic viscosity, ν, ranged between 0·0000285 and 0·0000155; and, taking that extreme range and assuming the value of vm as 0·695 feet per second multiplied by 0·55 for the hydraulic mean depth, the value of C determined from the above equation ranged from 93 for the highest viscosity to 102·2 for the lowest viscosity—a difference of about 10 per cent. The experiments were on channels, not on flow over weirs; but he thought they showed that viscosity had quite a marked effect upon the flow. He did not suggest that that vitiated in any way the results shown by the Authors, since the water in the reservoir would presumably be practically clear, but he thought the equations for the flow over weirs and through orifices as well as along pipes and in channels should be put in a form which contained the kinematic viscosity as one of the terms.

Mr. Roberts. Mr. C. H. ROBERTS wished to support other speakers who had asked Mr. Macaulay to give the results of the working of his new coefficient in the case of the Birmingham Waterworks. In 1913[1] Mr. Macaulay gave to The Institution some figures, with reservations, relating to the discharge of the drainage-area of the Birmingham Waterworks. The evaporation and percolation worked out at 18¾ inches, the average of 5 years. This figure appeared at

[1] Minutes of Proceedings Inst. C.E., vol. cxciv, p. 40.

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the time to be somewhat high in view of the figure of 14 inches very commonly used by hydraulic engineers; 12 inches appeared to be sufficient in some upland areas in Scotland. It would be interesting if Mr. Macaulay would state the result of applying the new coefficient, and say whether he now found that it was necessary or not to correct the previous figures given relating to the Birmingham works. Mr. Roberts.

Mr. S. C. LEWIS observed that he had been connected with the Birmingham works from their inception to their close, and more especially with the Caban dam. The crest of that dam was not peculiar, as the same crest pertained to the Pen-y-Gareg and the Craig-goch dams. Naturally he had had a good deal to do with the calculations of discharge from the drainage-area, and the question of what was likely to be the discharge over the dams. At the time when the Caban dam section was being prepared, it was considered that the maximum head that would ever come over the dam, assuming the length of the weir to be 600 feet, would occur with a free overflow of 3 feet. Later on, when in charge of the Caban dam, he was brought into personal relation with the floods that could occur in the Elan valley, and naturally made other calculations and endeavoured to see whether the actual results, as far as could be observed, tallied with the theoretical prediction. The biggest flood that occurred when he was there was in July, 1895, when 3·56 inches of rain fell between 3 p.m. and midnight. That flood caused considerable trouble, carrying away his temporary dams, and transporting timber and plant several miles. The next morning cross sections were taken at different places, and flood-marks were traced, to try to calculate the actual discharge, which appeared to have had a maximum value at any one period of flood of about 15 cubic feet per minute per acre off an area of about 45,000 acres. Later on, the question of erecting two abutments to the Caban dam, containing recording-apparatus and stairs, introduced a reconsideration of the discharge. It was proposed by means of the abutments to reduce the length of the weir from 600 to 566 feet. Ultimately it was decided to adopt a coefficient of 3·1 in a general formula. He had been interested to hear that Dr. Unwin gave a coefficient of 3·09 for the broad-crested weir. He could not possibly criticize the Authors' experiments; they had been carried out admirably, and it was pleasing to think that engineers would obtain some reliable information. He was glad to know that, even with imperfect data, the calculated discharge over the Caban dam was apparently nearly correct. Mr. Lewis.

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Prof. Dixon. Professor DIXON, in reply, thanked the members for their reception of the Paper. Mr. Macaulay and he hoped that the experiments described would be only the beginning of a series of experiments with the weir and measuring-tank. They had the permission of the Birmingham Corporation to carry out further experiments. Unfortunately the distance of the site from London and from Birmingham was a difficulty. Two or three days would be required to carry out one experiment. The dam at Nant-y-Gro and the measuring-tank were permanent. The only temporary work there was the timber flume. They hoped, therefore, that further experiments would be carried out with other weirs and other forms of sluice-gates. Mr. Macaulay had often urged that such experiments should be undertaken. Mr. Lindley had criticized the plotting of the results in *Fig. 4*. He had unfortunately forgotten that the point of the experiments was to determine their constant in a formula for a particular rock-faced dam, and so there would be little use in assuming an approximate formula and using it to check the results. The Authors agreed with Mr. Rice-Oxley that it would be interesting to determine the exact effects of the sides of the weir. In fact, two weirs were prepared, one (that used) being 3 feet wide, and another 1 foot wide, but when it was found that, as Mr. Rice-Oxley pointed out, the results would agree at least as far as the third place of decimals, and as the formula proposed would certainly give the minimum discharge, the Authors had felt compelled to postpone to some future date any further experiments, and to bring forward the results already obtained.

Mr. Macaulay. Mr. MACAULAY, in reply, said he regretted that he had not come prepared to speak about the yield of the gathering-ground. It must be remembered that the records of flow over the Caban dam (the crest of which was illustrated in detail in *Fig. 7*) had been taken since 1905, and to work out the yield shown by records of more than 20 years was rather a big undertaking in a busy Corporation office which was not over-staffed. There were other factors in working out yield figures that made him very chary about giving results until he had explored in every possible direction all the errors or all the factors which might tend to make them misleading. With regard to the very high evaporation figure referred to by Mr. Roberts, that was one of the factors which had led him to persuade his Committee to allow the experiments to be carried out. The only coefficient he knew of was Dr. Unwin's, and, with the greatest respect to Dr. Unwin, he had desired to know how far it applied to the Caban dam. The agreement had proved to be remarkably close, but the experiments were a means

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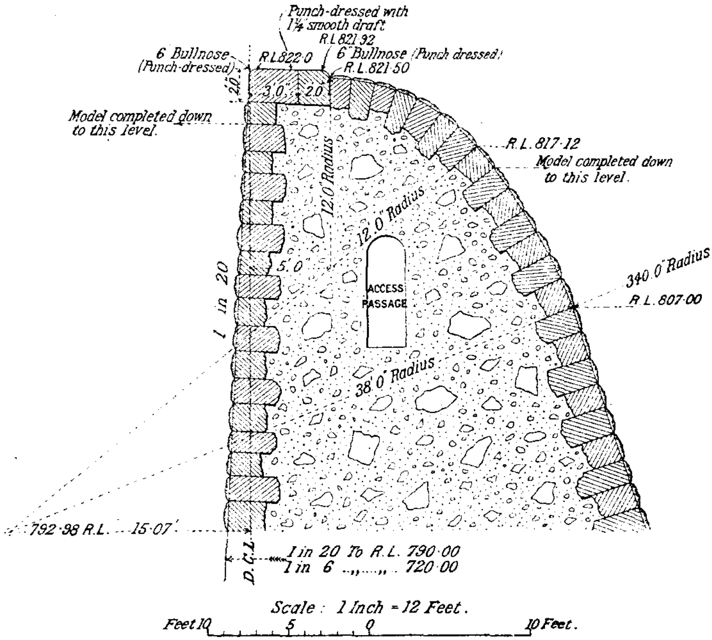
of eliminating possible error in that direction. As soon as he had the time to go into the yield figures closely he would be only too glad to give the results, because he recognized their importance. He had just completed a large, knife-edged weir of considerable length on the Claerwen, which was the unreservoired stream in the Elan valley, and he hoped to get direct measurements, over that weir, of the yield from 22,000 acres. Taking that with the weir discharges, he might be able to get somewhere near the truth in Mr. Macaulay.

Fig. 7.



CABAN DAM: CROSS SECTION OF CREST.

regard to the yield. He had a very able Water Committee to deal with, who would spend reasonable sums on such experiments. As far as the existing apparatus in the Elan valley at Nant-y-gro was concerned, he thought the Committee had spent all that it could be asked to spend, but they would welcome any competent experimenter who would come there and try to settle the many points that had been raised that evening, which might or might not vitiate the results of the experiments that had been carried out.

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