Mr. MANNING stated, that on being employed on the occasion referred to at the commencement of the Paper, he endeavoured to ascertain all that had been published on the subject of the rainfall of the district; and he found that the estimates varied from 33 inches to 18 inches per annum, and the compensation to be given to millowners was variously computed at from 5 inches to $9\frac{1}{4}$ inches flowing from the ground. As such uncertainty would lead to a conflict of professional opinion in Parliament, he considered the most proper course would be to appeal to facts, and accordingly he commenced the series of observations which he had just laid before the Institution. He felt the responsibility he had undertaken, because he was quite aware, he must not only be sensible, that he had presented statements which he believed to be true, but that he had neither stated anything carelessly, nor omitted the use of any means of insuring accuracy. He also felt that he ought not to conceal the slightest circumstance, whether it influenced the final results or not. He would, therefore, enter upon one or two matters which might need explanation.

In the first place he had given the record of the rainfall at Queen's College, Belfast, as being for 14 years; to be strictly accurate, it was the record for 13 years and 9 months, and for the other three months he had been obliged to get the record of another gauge. He had likewise given the observations of three rain gauges in the Woodburn district at elevations of 900 feet, 750 feet, and 300 feet, above the level of the sea, but to the gauge at an elevation of 750 feet an accident occurred on two occasions, so that he was not able to produce the precise results of that gauge, but the error could not amount to more than $\frac{1}{10}$th of an inch.

He had stated that all the observations of the flow off the ground had been calculated by the Lowell formula. That was substantially correct, but to insure accuracy, it was necessary to contract the dimensions of the notch. The notch was about one-fifth the width of the stream, with a waste board at each side to pass large floods. For if it were wide enough to give the quantities of large floods, it would not give with certainty the ordinary flow of the stream. Out of 730 observations of the flow of water, about thirty, being those of large floods, were not got by the Lowell formula, but by approximate methods; but as the whole quantity thus measured amounted only to 3·8 inches, even a very considerable error in their application could not affect the result in any appreciable way, and by using them no water whatsoever was allowed to pass unmeasured.

The matters treated of in the Paper might be classed as observed facts; the assumptions made in the absence of more extended observations; and the results deducible from those observations and assumptions. The observed facts were entitled to be considered correct with this qualification, that in respect of the number of cubic feet of water flowing down the river only one observation had been made per day throughout the year. The assumptions were two in number. The first was, that from the observations of the flow for one year could be calculated with sufficient accuracy the flow off the ground for a number of years—that was a matter which could only be disproved or substantiated by further experiment, the recorded experiments were for one year. Mr. Lanyon, the Engineer for the Belfast Water Works, finding the notches erected, and in working order, had continued the experiments for nine months longer, but unfortunately he had not taken the rain-gauge observations. Those of the flow, however, gave an opportunity of testing the accuracy of the methods adopted in the Paper in a very severe manner. The rainfall recorded at Queen's College, Belfast, from July 11th, 1865, to March 31st, 1866, was 25·96 inches. If that were increased in the proportion 1,176 to 1,000, the rainfall to be expected at Woodburn would be 30·54 inches, and calculating by the rules in the Paper, the flow off the ground would be 22·66 inches; the actual flow was 23·57 inches, differing from the theoretical flow by less than 1 inch, which was some confirmation of the soundness of the calculations. The other assumption was as to the ratio of the fall of rain; that between Belfast and Woodburn was taken as constant, not every day, or every month, but over a number of years. Then resuming on the 11th of December the rain-gauge observations which Mr. Lanyon had discontinued, the register at Queen's College from December 11th to March 31st was found to give 11·09 inches; following the ratio 1,176 to 1,000, this would give 13·04 inches, but adding only 16 per cent., as adopted in the Paper, the estimated rain at Woodburn would be 12·87 inches; the quantity actually observed was 12·85 inches.

He would now shortly state the general results. The rainfall at Woodburn, at an average elevation of 600 feet above Queen's College, Belfast, was from 16 to 18 per cent. greater. The rain at Woodburn at elevations of 900 feet, 750 feet, and 350 feet was nearly the same; the average of the three dry years was nearly $\frac{6}{7}$ths of the mean annual rain. The minimum rain was $\frac{3}{4}$ths of the mean annual rain. The evaporation or loss for the year 1864-5 was 14 inches; and this quantity might be expected to vary in different years, from $11\frac{3}{4}$ inches to $15\frac{1}{4}$ inches. The average flow off the ground was $24\frac{3}{4}$ inches. The average of the gross winter's rain was about 5 per cent. over the average flow off the ground in the three dry years. The storage depended, not only upon the absolute quantity proposed to be stored, but on its proportion to the total rain, and varied from 120 days to 430 days. For example, 20 inches required 175 days' storage, and 22 inches required 255 days, so that when it was said that a certain storage was required, it was necessary to know what proportion of the total rain was proposed to be stored.

As regarded the mills, it had been shown that at Woodlawn in 1865, 44 per cent. of the entire flow of the stream was consumed. The wheel was constructed to consume at full work 1·78 times the mean flow of the stream, that was, the mean annual flow of the stream was just 800 cubic feet in a minute, and the full quantity the wheel could consume with buckets two-thirds filled was 1,400 feet. If the wheels were reduced in size, there would be a less per centage, in the proportion stated in the Paper.

Mr. J. F. BATEMAN was afraid he must, to some extent, differ from the conclusions arrived at; not as to the facts, but as to the mode of using them. If he understood aright, the notch was made of the same width as the stream, and then the Lowell formula was applied. He thought that formula was as nearly as possible equivalent to the ordinary coefficient of 5·1 for the velocity of water discharged under pressure; the mean velocity over a notch or weir being two-thirds of that amount. He knew from experience that if the notch was as wide, or nearly as wide as the stream on which it was placed, the flood water could not be measured in that way, and could not be included in the total quantity which flowed from the ground; it would be considerably larger than any calculation deduced from the depth flowing over the notch. The water, at such times, was so great in volume, and approached the notch with a velocity so much greater than that apparently due to the measured depth, that no correct deductions could be arrived at, by the application of any ordinary formula. Then again, observations taken only once in the day, might exclude, in many cases, a large amount of flood water. The floods of the Woodburn district at this maximum amounted to 400 times or 500 times the ordinary flow in dry weather, and though the flood frequently remained only for an hour or two, or not so long; yet during the time it continued, it carried a large volume of water, which, if not included in the single observation of the day, was necessarily omitted from the calculation; therefore he thought it probable, that the quantities of water which resulted from the measurements recorded in the Paper were below the real amounts. He was aware there might be an error the other way, through two or three heavy floods having been accidentally included, when the measurements were taken. He had, however, no doubt, that the observations were as correct as any of the same kind could be, unless made day by day from a reservoir, or large surface of water, where the objection to the use of the ordinary formula would not exist. The Author was perfectly right in the course he pursued, if he wanted to ascertain the probable state of things in districts where there were no records of the annual difference in the fall of rain between one place and another, or in the case of one place, where the observations extended only over two or three years, and another where the series were continued for a long period of years. In such cases the only way in which a conclusion could be arrived at, was by assuming the difference observed upon one year, or two, or three years as a tolerably constant quantity; but that might in many years be erroneous. Therefore the deductions, though carefully worked out, must be taken as approximate only, and could not be depended upon as a general rule. With reference to the mills, the instance given was that of a large water wheel, which, being of an unusual size in proportion to the stream, was able to consume a large portion of the descending water. But that portion must not be taken as the quantity which could be most usefully applied to the wheel, because it was the amount between exhaustion one day and repletion another. A regulated daily quantity of water, much less than that which was required to work the wheel at its full power, would have been more beneficial in the working of the mill than that alternate deficiency and excess. In all experiments of this character, however, it was important to note the geological structure of a country, and the Woodburn district was remarkable, the chalk being indurated into an extremely cavernous limestone, by the heat resulting from the eruption or protrusion of the overlying basaltic, or trap rock. The water which entered the crevices and various swallow holes was impounded and re-delivered in small quantities regularly and constantly throughout the year, so that a large supply was stored for mill purposes, and given out more uniformly than could have been the case had the district been a hard, unbroken surface, allowing the water to flow over and off the ground instead of into and through it. That accounted for the peculiarity of the mill power being large, though the wheel was large in proportion to the volume; but it was an additional reason why these circumstances should be kept in mind, when conclusions were drawn with regard to different parts of the country. Still, the observations were useful, as showing the proportion of the whole amount of the stream which a water wheel so constructed was capable of employing. Indeed, with the modifications he had pointed out, all the investigations of the Author were exceedingly valuable. He was happy to find, as being responsible for the Belfast Water Works, that the results shown in the Paper were so nearly the same as those which, in the absence of those careful gaugings, he had himself assumed from the best information the country afforded. When he first reported upon those works fifteen years ago, before he knew what the actual rainfall was, he estimated what would be the results of various quantities. And as his experience of the district was enlarged he brought down the quantity as varying from 18 inches to 24 inches.

Mr. Beardmore quite admitted the difficulty of gauging floods, for the water at such times might pass by without record. In some cases he had adopted a mode of gauging during flood, by turning the notch into a sluice, by lifting the notch-board, and registering the height of both the head and the tail water. When the water began to head, and to push through the notch, it was better to endeavour to take the notch away, either by drawing the board, or by closing it and drawing a side-gate; the upper and lower gauges would then give the sectional area of water passing, and to calculate the quantity of water by the fall was then a simple matter.

He had tried gauging into boxes, as against calculation over a notch or weir, when the water was wire-drawn in approaching the notch, and the formula was thrown out a good deal. But it was quite easy to ascertain the velocity of a stream approaching a weir in flood, by having two gauging-posts, and placing them, with the lip of the weir for zero, in such a position as to give the depth flowing actually at the weir, and the depth at any given distance from it up the centre of the stream. If required, a third gauge could be placed so as to obtain the curve that the water assumed when approaching the weir; that would give, by calculation, the velocity of the approaching current, and the additional gauging would be a check upon the observations, besides indicating at once when the water rose above its normal volume, and consequently when the overfall formula became liable to correction.

With regard to the frequency of gauging, no doubt it would be better if the flow were taken at least three times per day; but he believed the Author had selected the time when the stream was least affected by the working of the mills, or by other circumstances, so that the result was fair—the stream being, to some extent, equalized by the mill-dams above.

Next, as to the mill question. Those mills worked under the Factory Act, and consequently had ponds, by which the night-water was stored, so that the power would be adjusted to nearly double the usual flow of the stream; but, though it had been objected that the Woodlawn wheel was of rather a high power, that circumstance only enabled it to do fairly the amount of work which the stream would give with the assistance of the pond. It was an important fact that, while the stream might be called high-powered, yet as much as 56 per cent. ran to waste, so that the Woodburn district gave a satisfactory example of the large quantity of water available in certain cases. The geological formation of that district was remarkable in one respect; the hills were capped with a vast bed of columnar basalt, under which reposed the hard crystalline chalk. The water falling in the back country was absorbed into the strata beneath the basaltic rocks, and, passing through the cavernous chalk, came out in the form of springs on the face of the slopes rising from Belfast Lough.

There was one valley of considerable area, terminating in a swallow called Lignaca, where the water disappeared, at the northern side of the hills, to reappear on the southern face, at two or three miles' distance, there forming copious springs, which, if not now, he hoped would be hereafter taken for the supply of Belfast or some future city. That was the largest instance of a subterranean flow he had ever seen in these islands. It was a large, perpetual stream, and not like the swallows in Hertfordshire, where, for the greater part of the year, there was no stream.

Whether the calculations deduced from observations of twelve months' duration, established an absolute proportion between the gauges and the long series of rainfall observations at Belfast, was open to doubt: but it was remarkable that the Woodburn hills gave a very uniform amount of rain, and a short series was thus fairly comparable. The rain beat against the steep face of the hills, which were not high enough to prevent the clouds passing over; there was not, therefore, that inequality of fall which occurred with higher ranges. And there was an internal proof of accuracy in the record of the fall at the several elevations mentioned having been tested with that at Belfast; the Belfast gauges being known to have been kept with accuracy for many years. The proportion of flow between the several months was very consistent with the observations he had himself made in other districts of the same geological character, but where the rainfall was much less in the course of the year. During the three winter months of November, December, and January—and sometimes February—there flowed from the ground nearly as much rain as fell; therefore it was not surprising that for two of the months, when there was generally even more water than a rain-gauge would show, the Author should have given varying amounts. Those months were influenced by falls of snow, which were difficult to ascertain correctly. The Paper established how much water could be obtained, and how much there still was to spare where mills were extremely high-powered, a state of things that prevailed very much in the south of England, where, although there was nothing like the same amount of rain, there was a large surplus of flood water.

Mr. S. C. Homersham agreed as to the necessity of having extremely large reservoirs, if the whole flood water that flowed off a district was to be impounded. Practically, it was impossible to make the whole of the water that fell upon steep hills, of an impermeable character, available. He was also of opinion that, where an account of the actual rainfall in a given district, for a lengthened period, could be obtained, the results were more accurate than when based upon assumptions. If the rainfall of one district was ascertained for one year only, and then compared with that of another district where observations had been made for a series of years, the results might not be accurate, or even approximately accurate. That fact was well ascertained from numerous returns, made on an extensive scale and long continued. He understood from the Paper, that the Woodburn observations upon rainfall were made with a gauge having a float and graduated staff, and he begged to inquire whether the staff rose above the surface of the gauge.

Mr. MANNING said, the staff was only used for a moment at each observation, and was then removed. The size of the hole through which the rain passed was about half an inch. The size of the float, in comparison with the area of the rain gauge, was small.

Mr. HOMERSHAM believed that the indications of such a gauge would be accurate. He had been desirous of knowing whether the staff rose above the surface of the gauge, because observations made with rain-gauges so constructed were not to be relied on. With the gauge actually employed, only a small surface of the water contained in the gauge was covered with the float, and there was also a small hole above the water in the centre of the gauge. It had been erroneously stated[1] that, if the water was thus exposed, a large portion would be lost by evaporation. He had made experiments very carefully, in order to ascertain whether that would be the consequence of using a rain-gauge so constructed, and he had found that no such loss took place; and, he might add, that rain-gauges similar to those used by him since 1847, were now generally employed by meteorologists.

Mr. ROBERT RAWLINSON, C. B., thought the experiments, however careful and laborious, were on too limited a scale, and extended over too short a period to enable any practically useful application to be made of them to general principles, and would, therefore, reserve his observations for an occasion upon which the whole question of rainfall and water supply might be adequately discussed.

Mr. C. GREAVES remarked, that the district in which the observations were made, was one which must be characterized as very moist, and that the amount of loss calculated by the Author was really to be treated as the amount of evaporation, mostly from the surface of the ground, leaving a large remainder available from the rainfall. In the Thames and other rivers in the home counties, not more than 25 per cent. of the whole rainfall could be registered, the evaporation amounting to 75 per cent. Rain-gauges were now multiplied all over the kingdom, and observations were

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vii., pp. 287-8.

made in every direction; but the process and result of evaporation had not been sufficiently studied. It was quite as important a subject as rainfall.

Mr. M. SCOTT was much struck with the circumstance that all the Woodburn gauges, set at varying elevations, of 900 feet, 750 feet, and 300 feet respectively, seemed to give nearly the same amount of rainfall, which was not consistent with his own experience in other districts. His observations went to prove, that as the elevation increased, so did the quantity of rain, up to a height of 2,000 feet; and that a gauge placed close to the surface of the earth collected more water than one placed several feet above the surface.

Mr. C. E. CAWLEY considered that no reliance could be placed upon the storing up of extra floods for the supply of a town. With regard to the utilization by mills, although he had no doubt it was quite true, that a constant was more valuable than an intermittent supply, yet it should be considered that where a wheel consumed a considerable quantity beyond the minimum, or beyond the average flow, the mill must be provided with other power, to be applied when the supply of water was not sufficient. That must be done either by means of steam power, or by storing water, to be used during the minimum flow. But though, theoretically, power thus obtained was not so valuable as that produced by a regular current, it by no means followed that such a wheel was compensated by giving a constant supply of one half, or one third its capacity, although that might equal the average it had used. He considered, however, that a greater number of facts must be collected before the question could be fully discussed.

Mr. MANNING in reply, said he agreed with almost all the remarks that had been elicited during the discussion. He thought, at the same time, there were one or two points which he could not permit to pass without notice; for if admitted, their tendency would be to invalidate conclusions which had been arrived at with great care and labour. It had been stated that his observations were, after all, only approximate, as the "velocity of approach" had not been considered, and there had been only one observation each day, but that, nevertheless, the results accorded closely with those which had been arrived at without experiments. In reference to the subject, he found the following statements in a printed report upon the supply of water to the town of Belfast.[1] At page 11 it was stated that 24 inches of rain could be collected; at page 14, 30 inches; at page 18 there was a table showing the supply to be derived from available rainfalls

[1] *Vide* "Report on the Supply of Water to the Town of Belfast." By John Frederick Bateman, C.E., F.G.S. Manchester, 1856.

of 36 inches, 30 inches, and 24 inches: however, at page 19, it was observed that, as the mills were to be first supplied, it would not be prudent to depend on more than 24 inches; but again, at page 21, the quantity which might be relied on, even after a succession of dry seasons, was stated to be from 27 to 28 inches. In 1855, the former calculations as to the probable quantity which could be obtained for the Woodburn rivers was somewhat modified; but at page 25 the future supply was estimated as likely to exceed 27 inches. In a Report published in 1864, in which the merits of two rival bills were discussed, the estimated supply was 18 inches. With regard to the compensation water, at page 19 it was stated to be $9\frac{1}{4}$ inches, which was nearly identical with the result obtained for 1864-5, by himself. At page 25, the quantity given was only 5 inches, and in the report of 1864 it was about 6 inches. As to the storage, it was stated at page 15, that for an available rainfall of about 30 inches, the space requisite for impounding all the water of wet seasons, so as to insure a regular average quantity at all periods, should be from 30,000 to 40,000 cubic feet per acre—from 100 to 135 days' supply; at page 20 this was increased to 150 days. If by the words, "all the water of wet seasons," &c., it was meant that the total average flow was to be stored, 431 days, and not 150 days, would be required. As to mill power, it was quite true that the supply, if variable, was not so valuable as if it were constant; but when it was suggested that the dimensions of the wheel should be changed for each variation in the supply, it appeared to have been forgotten that auxiliary steam power might be applied, and the water wheel worked at full power for as many hours each day as the supply would allow; that was the arrangement at Woodlawn, and at nearly every other mill in the district.

With reference to the formula, he agreed, that by supposing a notch, of only $2\frac{1}{2}$ inches width, with $12\frac{1}{2}$ inches, or any greater height of water running over it, the results given would be absurd, and that therefore, in strictness, it could not be taken as a general formula; but that was just what Mr. Francis, the author of the formula, said it was not. He gave, on the contrary, several conditions under which it must be used; one being that the length should be equal to, or greater than three times the height. But even taking the formula as general, it did not follow that because values for L and H might be substituted, which would make the term of the equation between the brackets vanish, or become negative, that the formula would indicate, as had been stated, a total cessation of the flow, or a reverse flow. He would add that the formula

$$Q = 214\ L\ \sqrt{H^3}$$

had been represented as giving the quantities due to the full force of gravity, without any allowance for loss of velocity or contraction, but that remark was equivalent to denying that the velocity of water issuing from an orifice was proportional to the square root of the height, a principle which had been accepted as correct by all hydraulicians for more than 200 years, and the truth of which might be demonstrated in various ways.

He had not intended, however, to investigate formulæ for the discharge of water, but merely to use a well-established rule for calculating the flow off the ground; but as the subject had been left in an unsatisfactory state, he would offer some remarks on those formulæ in an Appendix. He would add that the width of the notch was about one-fifth that of the stream above it; he had not taken into consideration the velocity of floods, but he believed the quantity stated was very near the quantity discharged.

Mr. FOWLER, President, thought the Author deserved the thanks of the Members for the careful and exact data he had presented to the Institution; and he hoped that a Paper would be prepared on this subject, which would afford scope for that ample discussion which appeared to be desired.

May 1, 1866.

JOHN FOWLER, President,
in the Chair.

The following candidates were balloted for and duly elected:—JAMES RICHARDSON FORMAN, WILLIAM HUSBAND, THOMAS MEIK, WILLIAM RICHARD MORRIS, and JAMES MUIR, as Members; HENRY BESSEMER, WILLIAM BROOKES, ROWLAND BROTHERHOOD, JOSEPH GREEN COOKE, JOHN CUNDY, FREDERICK GEORGE FINCH, CHARLES GOOLDEN, M.A., HENRY GEORGE CLOPPER KETCHUM, WILLIAM CAREY LEECHMAN, MARCUS SMITH, and MATTHIAS ERASMUS WESLEY, as Associates.

The discussion upon the Paper No. 1,153, "On the Flow of Water off the Ground, &c.," was continued throughout the evening, to the exclusion of any other subject.
