

### Discussion.

Sir Dugald Clerk.

SIR DUGALD CLERK remarked that he had read the Paper with much interest and was very glad indeed to find that so much work was being done in India. During the war he had been Chairman of a Committee of the Conjoint Board of Scientific Societies of Britain, which was dealing with water-power in the British Empire. The Committee, which sat for about 3 years, was fortunate in getting information from every part of the Empire. It came to certain conclusions, which were interesting in view of the Paper before the meeting. The first conclusion was that the potential water-power of the British Empire amounted in the aggregate to at least 50 to 70 million HP. Second, that much of that power was capable of immediate economic development. The Committee gave the rather wide limits of 50 to 70 million HP. because certain industrial factors would decide the exact proportion that could be used; but certainly 50 million HP. was available. Third, that except in Canada and New Zealand and, to a less extent, in India, Tasmania, and New South Wales, no systematic attempt had been made by any Government Department to find the true possibilities of the hydro-electric resources of its territory, or to collect the necessary data. That deficiency the Author was now helping to overcome. The Committee obtained valuable information provided by Mr. J. W. Meares, M. Inst. C.E., and several Reports, given by him and others, had been published. The fourth conclusion was that the development of the Empire's natural resources was inseparably connected with that of its water-power. The fifth was that the development of such enormous possibilities could not be left to chance, but should be carried out under the advice of some competent authority. The Committee went into the matter in as detailed a manner as possible, and its report gave only a summary of the information obtained. The information at its disposal included the water-power of Britain. He had estimated in 1915 that the total motive power of the world was 120 million HP. Professor Gibson also had made a similar estimate. That figure, of course, would not be greatly increased at the present time. It was necessary to remember, however, that most of that power in the world was obtained from combustion in various forms; and engineers had to look forward to a time when

coal would be scarce. So far as Great Britain was concerned that time was not more than 400 years hence; but in America it was considered that the coal resources would serve for 5,000 years. The problem of running the world when coal and oil were exhausted would ultimately have to be considered. In Britain there was rather more water-power than had been estimated at one time. The Committee made out that 450,000 HP. was obtainable from water in England and Wales, which included rivers and slow streams as well as streams in the hills. In Scotland 400,000 HP. was available; in Ireland, 500,000; and the Severn tidal scheme could furnish 400,000 HP. Therefore the total continuous water-power in Britain was  $1\frac{3}{4}$  million HP. The ordinary estimate of steam and other motive power of all kinds at the last census of production in 1907 showed that there was then, in Great Britain and Ireland together, about 11 million HP. in different forms. The  $1\frac{3}{4}$  million HP. of water-power might be considered equivalent to 5 million HP., if some method of balancing supply and demand could be found. Some sort of storage would be necessary. He had heard of attempts to introduce into some experimental stations storage of high- and low-pressure steam. The question was an interesting and most important one, and he welcomed the Paper. He could not speak on the subject in detail, but he recognized its importance; and he thought that by-and-by, when water-power was really required all over the Empire, it would be possible to obtain 120 million HP. The water-power of the world was considerably more than 120 million HP.—probably nearer 200 million HP., and, when the shortage of coal and oil began to be felt, water-power would prove a great asset to the engineer.

Mr. ALFRED DICKINSON thought the Author had rendered good service in clarifying the points to be considered in the design of water-power schemes. He made it quite plain that each scheme had to receive special consideration and treatment. To found a hydro-electric scheme on generalization was not sound engineering. Before the data for a certain hydro-electric scheme had been put forward, several years were spent in close investigation; and that investigation had shown that the catchment-area and discharge presented abnormal conditions. The scheme had been founded on the knowledge acquired, and as the Author had been resident engineer of that scheme he would remember that an engineer in Bombay, who based his advice on generalization, ignoring the special conditions, had startled the board of directors by a statement that the water available would be 35 per cent. less than actual investigation had shown it would be. The actual results in working showed, however,

Sir Dugald  
Clerk.

Mr. Dickinson

Mr. Dickinson, that his estimates were wrong. The three diagrams accompanying the Paper should be of great service to those investigating hydro-electric problems. Water-power undertakings had a fascination for him, but, notwithstanding that fact, he did not believe that all hydro-electric schemes were financially feasible. The consumer had little interest in the method of production, his one and only object being cheap power: therefore a hydro-electric scheme had no interest for him unless it could produce cheaper power than was obtainable by other methods. He thought a great deal of nonsense was talked about the possibilities of large hydro-electric schemes in Great Britain and Ireland. He would like to see them developed, but he did not think it was possible to develop them to compete with other methods of generation. In countries like India, Canada, Tasmania, New Zealand, the land for storage, transmission-lines, etc., was so cheap as to be almost a negligible item. In the Tata hydro-electric scheme the power for 9 months of the year was obtained entirely from storage. The water impounded would fill a canal 6 feet deep and 16 feet wide which would encircle the earth. That was an illustration of the space required to impound water; and that storage was with 1,740 feet head. Would any large scheme in Britain work under a head of 10 per cent. of that figure? Engineers who were interested in schemes for the supply of water to municipalities would know how costly the impounding of water was, and what opposition was met with from the riparian and other interests in this country. The opposition in Parliament was also great, and the cost of obtaining a Bill in this country to authorize the impounding of large quantities of water might be as much as the cost of the works for impounding in a country like India. Therefore he did not think engineers must look too much to Sir Dugald Clerk's figures for help in providing power. Sir Dugald Clerk had pointed out that the figures were for a 24-hour load. It was difficult to get labour to comply with existing conditions; and, if it were necessary to make power-consumption for industrial purposes follow a perennial river, the problem would be more difficult than ever, particularly as at the present day there was more coal in Great Britain than could possibly be used there.

Mr. Meares, Mr. J. W. MEARES remarked that he was pleased to have the opportunity of saying a few words on the Paper, because he had done pioneer hydro-electric work in India, before Mr. Dickinson introduced his vast schemes of storage. He had put up the little installation at Darjeeling, which was the first such installation in India, and which had led to a good deal being done since. Before

he retired, it was his privilege to look after the Hydro-electric Survey, Mr. Meares which had collected data from which he hoped there would be vast developments in the course of a few years. Such things inevitably took time. In many ways India was rather a backward country, but nevertheless the water-power was there, and, as industry arose to take up that power, it would be able to develop. Except in the Bombay Presidency all the best water-power sites were hopelessly out of reach of all industrial areas, and that was a leading economic feature of the country. The best water-power sites he had found were not a matter of 100 miles only, but a matter of many hundred miles, away from any possible place that could utilize the outputs ; and, until transmission became practicable over very long distances, some of the best water-power sites would have to remain undeveloped. However much the science of transmission developed, the fact remained that wires and posts would always cost a great deal of money. Hydro-electric engineers were enthusiastic over the low cost of running the works, but were apt to overlook the very heavy costs of transmission, which meant, in this country, that power from fuel was far cheaper. A good start had been made in India. Leaving aside the small installations in hill stations, an example had been set to the rest of India by three great Bombay developments, the third of which would be in working order in a year or two. The Cauvery scheme also was very successful. The Author mentioned the Kashmir scheme and gave a figure of 5,360 HP. ; but really the less said about the Kashmir scheme the better, because when he was there the load was, he thought, 250 HP., and he did not think it had ever exceeded 1,000 HP. That scheme had never justified itself. The plant was there—some of it falling to pieces—but there was practically no utilization of the power. Consequently he was a little apprehensive about a scheme that was being projected in the Punjab at the present time. A keen engineer had been making for surveys various schemes and hoped to carry one scheme out, but whether the load would be found or not was another matter. Bombay and Calcutta had ready-made loads, but the latter had no water-power within 300 miles. The Punjab had a few small industries, but whether they could be combined economically so as to be supplied by a single water-power scheme, developed on a very large scale, was a little doubtful. The advantage of water-power in India was that the transit costs of coal over the long distances were very high. For instance, up in the hill stations, if any industries existed, coal could never possibly compete with water-power, on account of the cost of carrying coal up 7,000 or 8,000 feet. The Author suggested storage rather than head as the best basis for classification. It did

Mr. Meares. not really matter very much, but Mr. Meares thought head was distinctly the better basis of classification, because storage was then considered merely as a sub-heading of the high-head schemes. Artificial storage was hardly ever possible on schemes of low head, or even medium head, because the volume to be impounded was too vast unless an area was laid out by Nature for it. In the Norwegian rivers, where a long length of gradually sloping rapids was developed by a series of lifting dams, there was a considerable volume of day-to-day storage between one dam and the next; but that was a different matter from storage of the sort which had to carry over, as the Tata storage did, not only for 9 months of one year in the dry season, but also for one or two subsequent years, when the rainfall might be deficient. He did not think those questions of main and subsidiary storage were quite as clearly distinguished in the Paper as they might be. An important point was the classification of power in such a way that data from different countries could be properly compared. There had been some difficulty in putting down the figures for the Hydro-electric Survey of India, and finally he decided that the best thing to do was to take the Canadian basis of water-power and to work out the figures on that basis as far as possible, because they were at least comparable with the results that came from all over the United States also. But recently, in working out a new summary of the world's water-power from all the Papers read at the first World Power Conference, he had found it a difficult matter, because horse-power was mentioned with nothing to say what it was; indicated horse-power, brake horse-power, electrical horse-power, or kilowatts were given; the load-factor was not always mentioned; and some powers were for 12 hours and others for 24 hours. To get those figures to a common basis was a very difficult matter, and he hoped the engineering institutions would find some common basis on which it would be possible to state the value of a given water-power site in terms of some definite unit that was universally understood. The Periyar scheme was being talked about when Mr. Meares first went to India in 1896, and it was still being talked about. Various concessions had been given, but so far they did not seem to have come to anything. The difficulty was that there was an enormous reservoir built entirely for irrigation work, and, when water was not wanted for irrigation, the reservoir level could not be let down for power. All that the Government could guarantee, therefore, to those who asked for the concession, was 250 cusecs for 240 days in the year. That left, as a rule, 125 days without any prospect of water. There was another difficulty: the water was on one side of the watershed and was utilized for irrigation on the other

side by a long tunnel, built many years ago. The quantity of water stored above that tunnel was, no doubt, that which would give the best results in the ordinary way; but the net result was that it would be possible in an ordinary year to take far more water out of the reservoir through the tunnel for power purposes, if the tunnel were at a lower level: a huge volume of dead water was stored below the tunnel-entrance. He thought probably, in the long run, a suggestion that appeared in the first Indian Hydro-electric Report might be carried out: the tunnel would be fitted with an intake-chamber, the dead water would be pumped up the necessary 5, 10, or 15 feet over this intake-dam, and an immense increase in supply would be obtained from the dead water. This would be utilized for power with only about one-fiftieth of the total power being wasted (namely, say 20 feet pumping-head gross against 1,000 feet power-head). The yield of catchment-areas was a matter which, in this country, interested the municipal engineer but was not of so much importance with regard to water power. It was, however, of enormous importance in India: irrigation went hand-in-hand with water-power, but the former had to have first claim. Many individuals had studied that question and had endeavoured to arrive at the factors of yield, with greater or less success. It was an exceedingly difficult problem, involving extensive data, and practically none of the methods evolved brought in all those factors. Mr. R. B. Buckley, M. Inst. C.E., had once said to him: "If the run-off were known, it would be possible to say what the factor is; but not otherwise." It was very largely guesswork at the present moment. His first chief on the Hydro-electric Surveys, Mr. G. T. Barlow, C.I.E., evolved a method which he believed had in it the germs of a considerable advance, provided there were good discharge-data, not only of total rainfall, but also of intensity of rainfall, a subject on which he himself had contributed a Paper to The Institution in 1923.<sup>1</sup> There was no doubt that when the amount and intensity of the rainfall were known over a sufficient number of stations in a given catchment-area, engineers would very soon evolve a method of determining the proper yield. The Meteorological Department had examined the matter critically and had concluded that such an estimate would be very inaccurate, for various reasons. It had to be recognized, however, that, if four rain-gauges were put on the roof of a building and read every day, the results at the end of a year would vary; and when hundreds of square miles were concerned,

<sup>1</sup> "The Experimental Development of an Automatic Integrating 'Intensity' Rain-Gauge without Clockwork." Inst. C.E. Selected Engineering Paper No 2.

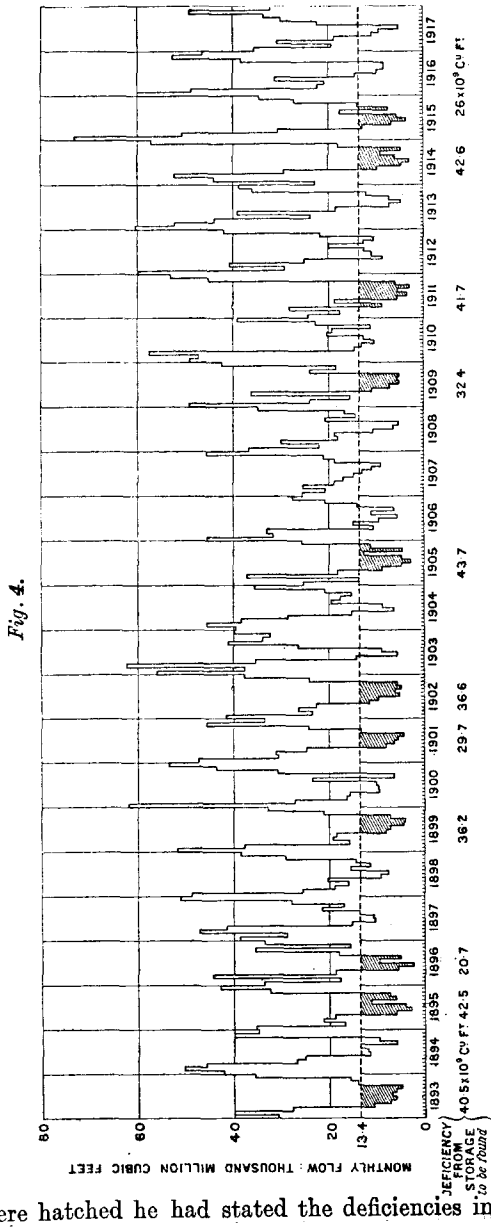
**Mr. Meares.** the variation was often immense. Although it was no doubt desirable to record rainfall to 0.001 inch, the last figure was of no value whatever from the point of view of catchment-discharge. The Author's plea for comprehensive collection of data in India was one every engineer who had been in India would thoroughly endorse. He himself had been called a nuisance for worrying the Government to get their engineers to collect data on various subjects; but the fact of the matter was that Government engineers had not time, and many of them had too much routine work to trouble about technicalities.

**The President.** The PRESIDENT said he had a pleasure given to him that evening which he had not anticipated when he came into the room. He had the privilege that evening of saying a word or two that it had never been possible for any President, during the hundred years of the existence of The Institution, to say before, owing to the fact that the first lady Student was present at the meeting that evening. He wished, on behalf of the members, to express to her their hearty welcome, and he hoped that, as she progressed in her engineering career, she would realize how courteous and considerate all the members of The Institution would be in helping her in every way they could.

**Mr. Stevens.** MR. THEODORE STEVENS expressed his appreciation of the concise and clear statements in the Paper and the able way in which it had been written. From his point of view he always desired primarily to know the capital cost of water-power installations, and his particular interest at the moment lay in a comparison between what had been done elsewhere and what was proposed in Ireland. The cost of hydro-electric installations in Norway had varied between £5 and £10 per horse-power. The river Tysse plant cost 5 guineas per horse-power, the Aura 8 guineas, the Nysset £9, and the Flaam £10. In New Zealand the Arapuni and Waikaremoana costs were estimated at £12 to £14 per horse-power. At Niagara the plants near the Falls, which worked under heads of 140 to 169 feet, had cost £17 to £23 per horse-power. A project, at that moment before a Joint Committee of the Irish Parliament, for the River Liffey, including 32,000 HP. in three steps (further steps might be added later) and transmission 23 miles to Dublin, was estimated to cost £37 10s. per horse-power. He had directed surveys of the rivers Shannon and Erne in 1915, and in 1920 estimated the cost, for the Water-Power Resources of Ireland Sub-Committee, at £43 per horse-power for 65,000 HP. on the Shannon, and at £29 per horse-power for 71,000 HP. on the Erne. Those were in four steps each, down the river-beds. The Liffey project, in which he was interested, was an extremely carefully-prepared scheme that was being advanced under the auspices of Sir John P. Griffith, Past-President Inst. C.E.

Incidentally the whole of the electrical work in connection with Mr Stevens

that scheme had been very ably done by Dr. Jeffcott, who was now the Secretary of The Institution. After the requirements of Parliamentary procedure had been complied with for the river Liffey, a scheme was put forward in 1924 for the Shannon to supply the whole country from a single power-house with electricity at a cost of a little more than  $\frac{1}{2}d.$  per unit. He had prepared a diagram (Fig. 4) of the flow of the Shannon, which showed the water needed for the ultimate development proposed to the Ministers of the Irish Free State, for about 275 million units per annum. He estimated conservatively that to produce sufficient to deliver that 275 million units would require an average discharge of 13.4 thousand million cubic feet of water per month; the deficiency was indicated on the diagram, and in those cases in which the areas below the 13.4 line were hatched he had stated the deficiencies in



Mr. Stevens. figures. In making his estimate he had made use of Mr. J. Chaloner Smith's Paper,<sup>1</sup> based on records of the forty-two sluice-gates across the Shannon and the weir parallel with the direction of flow, Killaloe to Ballina. He had also had the advantage of the calculations of the Public Works Department, carried out by Mr. F. J. Dick, M. Inst. C.E., who prepared estimates of flow in opposition to Mr. S. G. Fraser's Bill of 1900 for the development of 5,000 HP. on the Shannon. That scheme was not developed because, under the old Electric Lighting Acts, it would have been necessary to provide 5,000 HP. of steam plant to make up deficiencies. On *Fig. 4*, the 1905 deficiency was shown to be nearly 44 thousand million cubic feet of water—a quarter of the volume of water necessary in the twelve months for the 275 million units. The possible storage available in the Shannon was found by the Water Power Resources of Ireland Sub-Committee to be 10 thousand million cubic feet; and, in his opinion, that was the absolute limit of practicable storage in the river Shannon. It was proposed in 1924, however, to provide additional storage by means of walls on both sides of the lakes. The diagram (*Fig. 4*), showed that those lakes, which were 100 square miles in area, would have to be surrounded with walls 16 feet high, and he could not imagine how the land outside those walls would be drained. Such a proposal required very careful consideration by those in authority in Ireland before it could be accepted.

Captain von Heidenstam. Captain A. V. H. VON HEIDENSTAM observed that the main consideration in the development of water-power in India and elsewhere was, as the Author pointed out, the "all-in" cost per unit generated, according to the load-curve in each particular case, as compared with the cost of energy from other sources. At the present moment the chief other source for large industrial distribution of power was fuel; and the experience of recent years had shown a change in the relation of steam-generated power and water-power rather in favour of the former. He was referring to the improvements that had taken place in steam-turbines and raised their efficiencies, as compared with the rather stationary state of water-turbines. Great improvements could only be registered in the case of water-turbines for low heads. Furthermore, the possible margin for making improvements in the efficiency of fuel plants (now, say, 15 to 18 per cent.) was much greater than in the efficiency of the water-turbine (say 80 per cent.), and prudence dictated preparedness in that respect. That development had not by any means killed water-power, but it had led those who were con-

<sup>1</sup> Trans. Inst. C.E. Ireland, vol. xlv. p. 41, 1918-19.

nected with it to be very careful in planning the installations which were to compete with other sources of power. That care had to manifest itself in taking into consideration every possibility of storage, of which the Paper gave a good example, and also the possibility of supplying supplementary power, during load-peaks, from other sources, such as steam-driven plant, or by combination with other water-power plants or storage schemes. In Sweden, where he had been following the intense and highly-organized water-power development for many years, and in Scandinavia generally, the installations now under construction were being planned after the most careful investigations of cost, in connection with various possibilities not only of storage but of combinations between steam and water-power and between different water-power plants. The reply to the question of the best scheme could only be given from case to case: there was no hard and fast rule. The most detailed and specific investigations were required, and water storage was justified only when it was cheaper than other reserve or supplementary power. With regard to water-power in India, of which he had only a theoretical knowledge, he was sure that the question of the variation of flow was not so simple as in the cases of countries where more experience and data were available. Returning to the all-important point of cost, for the electro-chemical industries in Norway and Sweden it was calculated that a cost of about  $\frac{1}{4}d.$  per unit was a desirable, if not a necessary, figure. The question of the practical value of possible water-power sites in India, excluding the many non-economic factors, could only be solved in each case by discovering what the actual price per unit would be. It would be interesting to learn the actual cost per unit, calculated in the case which the Author had investigated in India, for various types of loads.

Captain von  
Heidenstam.

Mr. E. S. LINDLEY desired to discuss the subject from the point of view of the irrigation-engineer. The Author referred to combined irrigation and water-power schemes. In such combinations there was always a danger in compromise, and he suggested that it must always be decided which was the more important of the two. From the point of view of irrigation it had to be remembered that a storage scheme did not necessarily benefit irrigation if it increased the minimum discharge of the river at what might be the times of minimum demand, perhaps lowering the natural flow of the river at other times when the demand was greater. It only actually benefited irrigation-schemes if the increase of supply at critical times was proportional to the increase at the time of minimum demand. A pick-up weir might be made in some cases above the head-works of the canal with small storage that would slightly

Mr. Lindley.

Mr. Lindley. balance the variation between the irrigation and the power discharge. It would be of interest to estimate roughly the value of irrigation use of the water. Mr. Stevens had just cited figures for the cost of construction of a number of plants which showed an absolute minimum of £5 per horse-power. The scheme that the Author considered in detail provided for storage of 5,300 million cubic feet, which levelled the discharge of the river up to 204 cusecs. As nearly all rises above this discharge were eliminated, it was the minimum capacity for which an irrigation canal could be built. In the Punjab, where water-rates were low, but duties fairly high, a cusec could earn Rs. 1,000 a year. As the scheme was of about 20,000 HP. capacity, irrigation would bring in Rs. 10 per horse-power, ignoring interest on the capital and running-cost of irrigation-works. Much had been said in India about developing canal power that was now going to waste. As a matter of fact, although the figures obtained by Mr. Meares's survey did not show very much usable canal power, he thought a more careful investigation would show that considerably more power was available. One difficulty with such schemes was that canals had to be closed at times of slack demand, not to conserve the water, but to avoid flooding, as many canals were not provided with escapes; but irrigation demand was now becoming more constant over the year, and, as a matter of fact, it was now becoming difficult to arrange the closures needed for repairs. One scheme, for which a concession had been given, covered plants on two separate canals, the assumption being that when the demand slackened on one canal, the other would not be affected. A point which he personally took every opportunity of urging was that canal power should not be given for industrial or other purposes which could not stand the closures to which canals were subject, and which therefore required steam plants as standbys; there were plenty of purposes to which canal power could be applied which would stand such closures. The Author asked for statistics. Mr. Lindley thought he must be aware of the Annual Report of the Bombay Government in which were published records of flow for all their dams; also of a Paper<sup>1</sup> published by the Central Provinces Government, written by Captain A. ff. Garrett, R.E., in which discharge-factors were dealt with. He did not quite like the way the Author stated the percentages in the Table on p. 4; for example + 43 and - 44 per cent., which were said to be in the ratio of 2·5; it was more scientific to state percentages

<sup>1</sup> "The General Theory of the Storage Capacity and Flood Regulation of Reservoirs." Government Press, Calcutta, 1912.

of the whole, that was 143 and 56 per cent. In dealing with large volumes of water, thousands of millions of cubic feet were clumsy units ; it might be possible to adopt the cusec-day as an alternative. One million cubic feet would be 11·6 cusec-days. If that were not sufficient, a cusec-year might be employed, which was 31·53 million cubic feet ; and one thousand million cubic feet was 31·97 cusec-years.

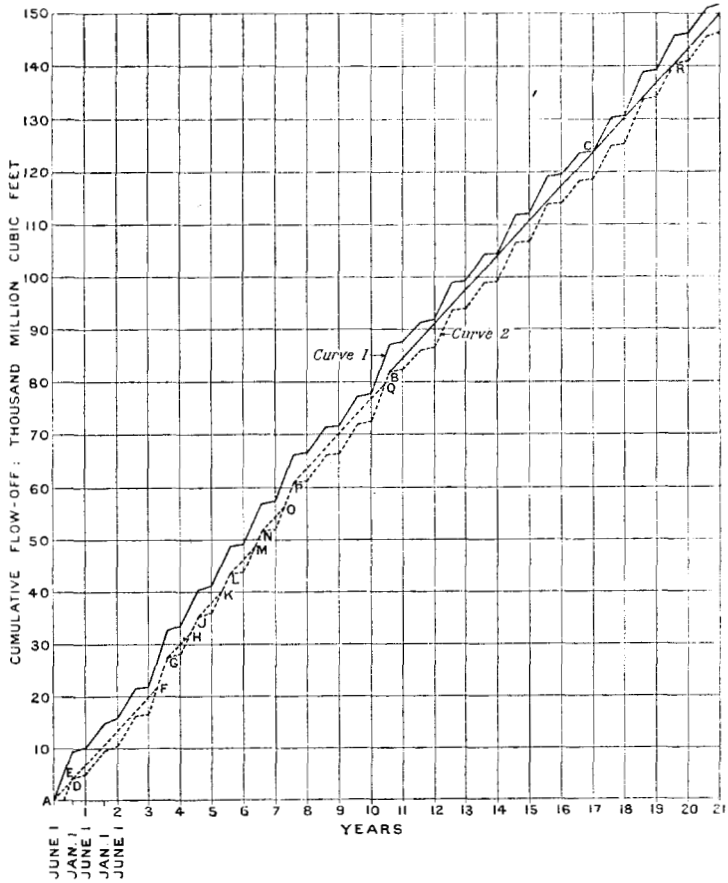
Mr. R. A. RYVES agreed with Mr. Lindley that in any question of combined hydro-electric and irrigation schemes it ought to be decided at the outset which was the more important. He thought that in few cases ought there to be any doubt on that point : one should be, not the more important, but definitely the dominating scheme. If the scheme was primarily for irrigation, most engineers were strongly against contemplating the use for industrial purposes of any power that could be obtained, unless that could be done at a later stage, when it was found that all the demands of irrigation could be satisfied. He had advised on that point a little while ago with regard to a number of schemes in which in some cases the storage-volumes were large, although the falls were not great ; and he had decided against employing any electric power for industrial purposes, partly because there was no industrial market within a reasonable distance, and partly because he felt it was a great pity, under the circumstances, to saddle the schemes with an additional complication of that character ; but he did recommend the contemplation of installing a small hydro-electric plant to develop power for certain purposes of irrigation. He had also in mind an area in Spain where there were good sites for reservoirs hundreds of feet above a fertile plain, but separated from that plain by rugged country through which it would be difficult and costly to make a canal, especially with the many falls necessary. He believed that area presented a favourable opportunity for using the water-power in an ordinary hydro-electric plant and allowing the tail water to flow down to the fertile plain below, where it would be pumped on to the land by the electric power already generated. Putting the matter generally, if a fall of, say, 20 feet was available near a dam, and the overall efficiency of the plant was 50 per cent., the whole of the water could be pumped to a height of 10 feet above the river-level at a place perhaps 100 miles downstream, where the ground might be more favourable for irrigation than near the dam. With the developments that were taking place in the transmission of electric power, there was hardly any practical limit to the distance at which an engineer might control the water if, instead of using a canal, he used a transmission-line, provided, of course, that the water

Mr. Ryves. flowing down the river to the selected area was not wasted. Part of the water flowing to a distant irrigation-area was usually employed for small irrigations on the banks of the rivers, but such areas could be developed, and the water was seldom actually lost. In a good many cases, too, compensation water had to be sent down. He could illustrate those generalizations by examples; but he simply wished to suggest to other engineers the feasibility of the proposal he had outlined.

Mr. Batchelor. Mr. E. BATCHELOR remarked that, in connection with a market for power in India, he gathered that Mr. Meares did not anticipate any immediate increase in the demand for power. On the 3rd February, however, the Government of Bombay had opened the first section of electrified railway, and it was anticipated that the work of electrifying the railway from the top of the Ghats to Poona and Igatpuri would be concluded within a year or two. It was probable that railway-electrification would be extended rapidly in India. He had had 25 years' experience in the Central Provinces, 20 years of which were passed in the Indian Civil Service, and had had considerable experience as a famine officer. Famine and scarcity in India were almost invariably the results of a deficiency in the rainfall and failure of the crops. In such times not only was less produce available for transport, but the purchasing-power of the people was also reduced, and undoubtedly that affected adversely the receipts of the railways from both passenger- and goods-traffic. Other industries also would suffer, as a result of famine conditions. Hence an electric-supply undertaking could reasonably anticipate a reduction in demand in a year of deficient rainfall. It would therefore *prima facie* be reasonable to design a hydro-electric project on the basis of utilizing more water in a year of excess than in a year of deficient rainfall. On this basis the balancing storage-volume required for the production of a given quantity of power would be somewhat less than that necessary for the same quantity of power with constant output. It was of interest to learn from the Paper that such had been the experience at the Tata hydro-electric works. Fig. 1, Plate 1, showed that the graphical representation of the behaviour of a reservoir depended a great deal on the selection of the year for beginning the examination of the changes in the storage. The storage at the end of the third year was 1,200 million cubic feet less than that at the end of the first year; and hence, if the beginning of the second year had been chosen for commencing the examination, the constant annual gross discharge possible with the same storage-capacity would have been reduced by 600 million cubic feet, or 9 per cent. Had the date chosen been the beginning of the 9th,

12th, or 17th year, the decrease would have been even greater. That difficulty was largely obviated, if a cycle in the rainfall had been established, by continuing the examination through the period of the cycle. He had had occasion to make many scores of such calcula-

Fig. 5.



tions as would be necessary, by following a method of trial-and-error, in the preparation of curves 1 and 2 of Fig. 2, Plate 1; and he had devised a graphical method, particulars of which had been published.<sup>1</sup> This method, when once the curve of the cumulative flow-off had been constructed by simple addition of the figures giving

<sup>1</sup> "Indian Engineering," vol. Ixix, p. 290 et seq.

Mr. Batchelor. the flow-off ("yield" in the Paper) for the constituent periods, enabled the determination of the data necessary for the construction of curve 1 to be effected with the aid of a ruler and a pair of dividers in a few minutes. The method also gave an equally simple solution of the reverse problem, namely: the supply being given, to find the minimum storage required to maintain that supply throughout the period under examination. As an illustration of the use of this method, the behaviour of the reservoir considered by the Author in Plate 1 was illustrated in *Fig. 5*. The problem was to ascertain the maximum constant annual discharge possible, with a storage of 5,300 million cubic feet. Curve 1 was the curve of cumulative flow-off, the flow-off being that for the period of 7 months, June to December, and 5 months, January to May. That curve was constructed from data given in *Fig. 1*. Curve 2 was identical with curve 1, but was separated from it by a constant distance along the ordinates, representing a storage of 5,300 million cubic feet. The second curve was drawn to facilitate the explanation of the behaviour of the reservoir, and was not actually necessary. To solve the problem it was necessary to draw in all lines, any one of which passed through an angle on curve 2, and, in a direction forward of that angle, an angle on curve 1, and also which cut curve 1 in a direction backward of the angle on curve 2 and did not cut it in a direction forward of that angle. The slope of the line which had the least slope—line BC—measured the maximum supply, namely, an annual discharge of 6,530 million cubic feet, which compared with the Author's figure of 6,460 million cubic feet. To examine the behaviour of the reservoir, a line was drawn through point A, parallel to BC, and cutting curve 2 for the first time in D. Thus the intercept of any ordinate between curve 1 and the line AD measured the content of the reservoir on the date corresponding to the ordinate. At the point D the content of the reservoir was 5,300 million cubic feet, and hence the reservoir overflowed. On the date corresponding to point E the reservoir began to empty. A line was drawn through point E parallel to BC, and cutting curve 2 for the first time in F. Then the reservoir began to overflow on the date corresponding to the point F, and continued to overflow till the date corresponding to the point G. The lines GH, JK, LM, NO, PQ, were parallel to BC; hence the reservoir overflowed in the 1st, 4th, 5th, 6th, 7th, 8th, 11th, and just became full in the 20th year. A comparison with *Fig. 1*, Plate 1, would show the correspondence between the results obtained by the two different methods. In *Fig. 1* the reservoir overflowed in the 19th year, but it would not overflow if the reservoir were empty in the beginning of the 18th year. The length of the

intercept of the ordinate through the point E and the line AD Mr. Batchelor. prolonged measured the quantity of water which ran to waste over the weir between the dates corresponding to the points D and E; and the same remarks applied for the pairs of points FG, HJ, etc. Further inspection would show that the lengths of the intercepts of the ordinates between curve 1 and the line BC and the lines parallel to BC reproduced the information given by the curve in Fig. 1. "Water stored in lake." He had shown<sup>1</sup> also how the curve of cumulative flow-off could be utilized to solve with the same facility problems connected with flood-storage and service-reservoirs. In the section (p. 9) dealing with "Conditions of Load with Annual Variation" the Author suggested two alternatives. If the second of those methods were adopted, the discharge in the year following a year of scanty rainfall might happen to be well above the average; whereas the demand for power in such a year would probably be well below the average. In connection with the determination of the yield of a catchment (p. 10) Mr. J. Glasspoole had stated<sup>2</sup> that the 35-year cycle had gained general acceptance amongst meteorologists, and he had shown that:—(a) For the British Isles as a whole, the range of the rainfall, the maximum and minimum each expressed as a percentage of the average for the period of 35 years from 1881 to 1915, was for 1 year, 58 per cent.; 10 years, 14 per cent.; 20 years, 7 per cent.; and for 35 years, 2 per cent. (b) The ratio of the maximum to the minimum rainfall for any of the periods was for 1 year, 174 per cent.; 10 years, 114 per cent.; 20 years, 107 per cent.; and for 35 years, 102 per cent. In small areas the ranges and ratios might be expected to be larger than those given, as was stated to be the case for the periods of 35 years. The difference between the variations for periods of 20 and 35 years, namely, 5 per cent., was sufficient to make a material difference in the cost of a work designed to store a high percentage of the yield. It appeared that the average for a period of 35 years was a more accurate standard even than that for a considerably longer period, unless the longer period was approximately a multiple of 35 years. The shortness of the period of 35 years gave good reason for thinking that the determination of the storage necessary to balance the yield might now be placed on a sure basis. With the establishment of the existence of a cycle in the rainfall in the past, and with the

<sup>1</sup> "Indian Engineering," vol. lxx, p. 108.

<sup>2</sup> "Fluctuations of Annual Rainfall; a comparison of 35 year rainfall averages over the British Isles for different groups of 35 years falling in the period 1868 to 1921." British Rainfall, part IV, 1923.

Mr. Batchelor. probability of small variations in the rainfall during succeeding periods—since it was reasonable to assume that the cycle would recur—it became justifiable to forecast the aggregate rainfall for a period of years, and to base the design of a reservoir on such a forecast, instead of basing the design on the rainfall of the past and assuming that, if the reservoir would have been satisfactory in the past, it would therefore be satisfactory in the future. If records for 35 years were not available for the catchment, the rainfall could be interpolated by correlation of known rainfall in the catchment with that of neighbouring stations. It was a matter for regret that there were large differences in the estimates of yield obtained by following different recognized methods of estimating the yield. Assuming that the cost of a work utilizing a large fraction of the yield was proportionate to the yield, a difference of 10 per cent. in the estimate of yield might result in a loss of £100,000 in the case of a work costing £1,000,000; and, as might be concluded from the Paper, differences in the estimates of yield made by engineers of experience might exceed 10 per cent. : for example, the classification of a “medium” as a “good” catchment, using Mr. Strange’s table, would result in an error of 33·3 per cent. The expenditure of a very large sum on the determination of the yield of the catchment should be regarded as an integral part of the development of a hydro-electric project. A map<sup>1</sup> prepared by Mr. A. T. Arnall, M. Inst. C.E., showed that the average annual rainfall on the catchment of the Tata hydro-electric works was about 175 inches. The yield was stated by the Author (p. 12) to exceed 80 per cent. of that figure, or 140 inches. The loss by evaporation and percolation was, therefore, less than 35 inches. As regarded loss by seepage, the Author had stated<sup>2</sup> that the loss by evaporation and seepage through the beds of the reservoirs had been found to be equal to a depth of about 3½ feet of water. Evaporation losses alone probably constituted a large part of this depth, and the loss by seepage alone appeared to be small. The average hydraulic gradient from the centre of the lakes, situated on the Deccan plateau about 1,800 feet above the power-station, to the Ulhas river at the foot of the scarp to the immediate west, was extremely steep, being as much as 1 in 7. Mr. Batchelor had noticed similar small losses in the cases of reservoirs situated just above high escarpments, not only on basalt, but also on sandstone formations. The smallness of the loss by percolation under such very favourable circumstances was noteworthy. The

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. ccvii, p. 88, Fig. 16.

<sup>2</sup> *Ibid.* p. 116.

Author's remarks on the subject of yield and "lag" raised doubts Mr. Batchelor. as to whether it was wise to attempt calculations of yield for short periods. Mr. Batchelor was inclined to think that 1 month was too short a period; in the case of India it was very doubtful whether it was advisable to take a period shorter than that of the monsoon. This period had been adopted in drawing *Fig. 5*.

The AUTHOR, in reply, thanked the President and members for The Author. the kind reception given to his Paper. Mr. Meares had stated that a feature of Indian water-power was that the best sites were generally quite out of reach of industrial centres. The Author agreed that such was unfortunately the case; but on the other hand there were many fine power sites within reach of districts which, from the point of view of transport-facilities and supply of raw materials, were eminently suited to the establishment of special industries. In the combination of irrigation and power, it was undoubtedly desirable, as several speakers remarked, that one interest should definitely dominate the other. As India was at the present time essentially an agricultural country, irrigation would and should, speaking generally, take priority over power. The point was, however, that supply of water for power must, within certain limits, be continuous and constant, while the discharge for irrigation purposes was usually variable and intermittent. The steady flow from a power scheme could therefore be used to furnish, when required, water for irrigation, thereby increasing to some extent the revenue of the undertaking; on the other hand, very few industries would lend themselves to utilizing power derived from a fluctuating and intermittent irrigation-supply, and the establishment of power works would only be possible where the irrigation authorities were able to specify definite limits of variation in the supply of water. There were cases, however, where conditions of high head, etc., rendered it economically possible to provide large storage for power-development where it would be quite impossible to do so for irrigation purposes. If the tail-water from such a scheme commanded irrigable land, then this furnished an instance where power and irrigation could be favourably combined. Having investigated the Periyar power project, he was able to express the definite opinion that, from an engineering point of view, a sound scheme was possible, favourable to the interests both of irrigation and power, when sufficient industrial demand for power arose. The scope of this Paper and the special conditions obtaining in India brought forward prominently the subject of storage. It would be clear that storage referred to in the Paper implied the storage required for the balance of annual and seasonal variations of the discharge. The question of day storage, often referred to as

The Author. "pondage," was here rather in the nature of a side issue, and had been purposely omitted. If a scheme was provided with storage so as to give a steady continuous discharge for power for 24 hours a day, it depended on local conditions whether it would be possible to give, say, three times such discharge for 8 hours a day, or to provide for other daily variation in the demand. If the storage was close to the power-station, then the day regulation would be done from the main storage, which would serve as pondage as well; if, however, the main storage was so distant from the station as to make such day regulation impossible, then day regulation would have to be met by providing pondage immediately above the power-station; and, if the natural features of the site did not permit of this, water would be lost to an extent dependent on the nature of the demand for power. The question of day storage did not affect the curves or methods of calculation referred to in the Paper; the question of main storage was considered first, and that of pondage separately. Mr. Batchelor went a good deal farther than the Author in his views as to the possibility of permissible variations in power-supply available. While it would be quite possible to allow certain defined annual or seasonal variations, conforming to the available water, in certain special industries, the Author did not consider that, from an economic point of view, it would be at all possible to assume that variation in the power-demand for general industrial loads would correspond at all closely with variations in the annual rainfall. The farthest he could go was to suggest that it might be unnecessary to provide for an occasional year of abnormally low rainfall, where the power was being utilized for some special industry deriving its raw material from crops, as in the case of cotton; but it did not appear at all possible to omit provision for the worst year where the power was required for lighting, railways, or other public services. Mr. Batchelor's remarks as to the starting point of storage curves emphasized the fact that storage-works could not be adequately designed on short-period records, and that it was desirable that the records should cover a rainfall cycle of years. The length of such cycles appeared to vary in different places; in the Western Ghats it was 22-23 years. The mass curve<sup>1</sup> or curve of cumulative discharge method, described by Mr. Batchelor, was well known to engineers engaged in storage problems, and was most useful; it had been used in preparing the curves in the Paper. Apart from the advantage of standardization of units, the question of using million

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<sup>1</sup> The application of the mass curve to storage problems was described in *Engineering News*, vol. 70, p. 1290, 1913.

cubic feet as a unit for storage, or cusec-days, or cusec-years, as The Author. suggested by Mr. Lindley, did not appear to be of material importance; anyone dealing with storage problems would prefer the unit to which he was accustomed, while anyone not conversant with storage calculations would probably find it quite as difficult to visualize a cusec-day as a million cubic feet. Mr. Meares's statement, that the allocation of discharge factors to a catchment was largely a matter of guesswork, was one which, the Author ventured to suggest, required some qualification. In so far as a figure which was not capable of exact mathematical determination might be characterized as guesswork, it filled that description. The discharge, however, depended on certain definite natural laws, and the guess should be an intelligent one, based on a proper appreciation of those laws; its accuracy would depend largely on the experience of the guesser. In regard to the relative costs of steam- and water-power, Captain von Heidenstam had referred to the great improvements in the efficiency of steam plants; but surely the development of the water turbine, both as to size and efficiency, had, during the past 20 years, been equally marked. How much farther the improvement in steam plant would go was a matter of interest, but the large water turbine had already reached so high an efficiency (over 90 per cent. in some cases) that there was no great room for further improvement. Future progress appeared likely to be in the line of development of the propeller type of turbine, whose high specific speed tended to economy in cost of both turbine and generator. Sir Dugald Clerk had given some very interesting figures as to the water-power resources of the Empire, and had referred to the value of water-power in relation to conservation of the coal-supply. The combination of comparatively low head, high cost of land, and almost prohibitive cost of large storage, restricted the possibility of any very extensive water-power development in Great Britain, and water-power did not appear to offer any very great prospect of coal-saving so far as home consumption was concerned. Sir Dugald Clerk estimated the life of Great Britain's coal-supply at 400 years. In view of the great scientific achievements in the past 400 years, it appeared perhaps not improbable that within this period chemical and engineering science might evolve some other method of obtaining energy, possibly on the lines of disintegration of the atom.