Correspondence.

Mr. G. P. ANDERSON considered that the official explanation given of the cause of the crack, and briefly referred to on pp. 420 and 421, was unsatisfactory, and submitted an alternative explanation based principally on changes of temperature. The official explanation, as propounded by Professor Hörnell, was that the rock swelled with increased moisture-content due to the head of water in the headrace. It was true that the rock would expand rapidly with increase of moisture when it was nearly dry, but the change became very slight as saturation was approached. It had also been shown that the rock was always practically saturated, even in exposed faces, whereas the floor of the headrace had previously been covered by a swamp. The great elasticity of the country rock had been referred to; the elastic moduli of the rock, concrete and steel were approximately as 1 : 10 : 100. At the time of the crack there were three penstocks in operation (cross section, Figs. 1, Plate 8) and three others complete but empty. As those penstocks were 12 feet in diameter, lined with steel encased in not less than 2 feet of concrete, they provided, relatively speaking, a very rigid reinforcement, extending from the power-house to the forebay, where it ceased abruptly just where the crack occurred. (Section *BB*, Figs. 5, Plate 8.) The 7th of June being almost mid-winter, it might be inferred that the penstocks, cooled by the water in them, would be in tension, tending to pull the intake-structure away from the forebay. That force, combined with the natural droop of the country towards the gorge and the pressure of the water in the forebay, would produce a concentration of strain where the reinforcement ceased. It might be open to question whether the penstocks had some initial tension due to the heat generated during the setting of the concrete; nevertheless, conditions were favourable for a crack precisely where one occurred. Mr. Anderson.

Mr. ERNEST BATCHELOR observed that it would have been of interest and value had the initial history of the Pykara scheme been given by Mr. Platts; apparently the site had been noticed many years ago. Mr. Batchelor.

The amount of power obtainable was given on p. 458 in an indefinite form, namely, as 90,000 HP. He considered that the power obtainable annually in a hydro-electric project should be given in horse-power-years. With full efficiency throughout, the 3,684 million

Mr. Batchelor. cubic feet available (132 square-mile-feet) with a head of 3,050 feet, could produce 40,000 HP.-years; with an overall efficiency of 80 per cent., the available output would be 32,000 HP.-years. (It was interesting to note that 1 "square-mile-foot" of water falling 1 foot could generate theoretically 0·1 HP.-year. That relation was exact, and he had found it of very great value in making calculations when prospecting for hydro-electric sites.) The Paper only contemplated the power obtainable with reservoirs storing approximately the estimated minimum yield in the past of the available catchments. More could be obtained with larger reservoirs, but, from p. 470, their construction did not appear to be contemplated. Questions of balancing storage would not arise.

It would have been of value had the nature, texture, depth, and porosity of the soil been described in some detail, since the loss by evaporation very largely depended on those factors.

No mention was made of reference to the meteorological authorities in Poona or Madras, but he presumed that the various rainfall statistics had been supplied by them. In connection with his own proposals for a new waterworks for Nagpur, C.P., he had suggested that the Director General of Observatories should be asked to prepare a map of the catchments giving contours, monthly isohyets and monthly isotherms; a similar map appeared to be necessary in the case of all works where an estimate of yield from a catchment had to be made.

From the description given of the Thalipuzha catchment, on p. 464, it appeared that evaporation in that catchment might be very different from that in the other Pykara catchments; its elevation was much less, and hence the evaporation was presumably considerably higher. He did not understand the sentence "Short-term statistics . . . concentrated rainfalls," on p. 465; he would have thought that with "concentrated rainfall" the loss by evaporation for equal rainfalls would have been less, not greater. For those reasons he did not think that the method adopted gave reliable results.

Nothing had been said as to the causes of the difference between the rainfall on and the yield of a catchment, which were not so obvious as they might seem to be. The chief of those causes were losses by evaporation from soil and vegetation, and by the percolation of ground-water outside the catchment. Loss by evaporation varied largely with the texture of the soil. A rational treatment of the problem of yield should endeavour to estimate those losses in concrete form, in terms of depth of water in inches over the catchment. In a Paper entitled "The Yield of a Catchment" [1] he had

[1] Original Communication No. 4790. Presented to The Institution in 1930.

endeavoured to describe such a rational treatment: it was based on the accurate observations of percolation-gauges at Rothamsted. That Paper also contained a treatment of the problem of the percolation of ground-water, a matter which had received very little attention in England, and as to which the Paper under discussion was silent. The estimate of loss by evaporation entailed the classification of the soil of the catchment, a classification with which he had been very closely acquainted in connection with settlement operations in India. He ventured to commend a perusal of the above-mentioned Paper to those who had to estimate the yield of a catchment. Mr. Batchelor.

With regard to regulation and storage, he did not understand what was meant by "90 per cent. of minimum year"[1] and "unit cost" in the headings of the Table on p. 470. It was curious that data of the evaporation-loss from a water surface were not available from observations of the reservoir in Ootacamund within the catchment. The total annual loss, namely, 54·3 inches (p. 471), was not much less than that at Nagpur in the plains, which was 63 inches.

He would suggest that the efficiencies of alternators, transformers, and transmission-lines should be given in the same detail as those of the turbines.

The total cost of the scheme was given on p. 494 as Rs.7,320,000, and the effective HP. as 21,800. On p. 458 it was stated that in the present development storage for only 84 million cubic feet had been made. That was only 3 square-mile-feet, which, with a head of 3,050 feet, and full efficiency throughout, would give only 915 HP.-years of energy. He did not understand how the figure of 21,800 HP. had been obtained: presumably additional storage was contemplated. Nothing was said as to the probable annual cost of the scheme. Would the Author give the probable cost of the power per unit, in varying quantities, at different load-factors, and at varying distances from the power-station?

Mr. J. M. Lacey observed, with regard to the Pykara hydro-electric development, that it was always a difficult problem to correlate the precipitation on a drainage-basin with its yield, as so many factors had to be taken into consideration; the physical and geological character of the basin, distribution and intensity of the rainfall, ground storage, evaporation from the soil and transpiration of vegetation, and the lag between rainfall and resultant flow. The dry-weather flow was also considerably dependent on the intensity and magnitude of the rainfall of the preceding wet season. For example, after the cyclonic storm on the basin of the Penner river, Mr. Lacey.

[1] See footnote *, p. 470.—Sec. Inst. C.E.

Mr. Lacey. South India, in November 1903,[1] during the ensuing dry weather the streams feeding the Penner ran for months, although there was no rainfall on the catchment. In normal years those streams were quite dry from January to June or July. Another factor to be considered, when the catchment-basin had some ground storage, was that when the superficial soil was quite "air-dry" evaporation from the soil was at a minimum. Early rains, by wetting the top soil, increased the evaporation from the soil, and the spring flow diminished or ceased altogether. That phenomenon had been discussed by Mr. R. F. Thorp, M. Inst. C.E.[2]

Where records of stream-gaugings were available, it was undesirable to neglect them in favour of estimated yields from perhaps imperfect data. On p. 467 the Author gave actual yields from the basin of the Pykara stream for the north-east monsoon period and for the dry-weather or non-monsoon period for the years 1925 to 1927. Comparing those actual yields with the Pykara rain-gauge record, the following figures were obtained :—

		Rainfall: inches.	Yield: inches.
1925.	S.W. monsoon	47·9	(uncertain)
1925.	N.E. monsoon	12·5	12·7
1926.	Dry weather	8·8	6·3
1926.	S.W. monsoon	54·8	(uncertain)
1926.	N.E. monsoon	7·2	8·1
1927.	Dry weather	5·6	2·2

The Table on p. 467 showed that, although a heavy south-west monsoon increased the yield of the following north-east monsoon period, there did not appear to be any great ground storage, as the yield fell rapidly during the ensuing dry weather, so that the greater part of the south-west monsoon rains flowed off the ground. For instance, the greater part of the rainfall of the south-west monsoon of 1926 (54·8 inches in 4 months) had evidently run off the ground, as the yield from the north-east monsoon was only slightly greater than the rainfall, and the yield rapidly diminished during the following dry-weather season. The Table showed the dry-weather flow to be dependent to a certain extent on the north-east monsoon rains.

The critical period was the dry weather from January to May, and from the Table on p. 467 April appeared to be the critical month. Turning to Table I (p. 459), although 1918 had the lowest rainfall, with a very low south-west monsoon rainfall, the following north-east monsoon was 6·7 inches more than the average. The year

[1] J. M. Lacey, "Floods in Southern India." Minutes of Proceedings Inst. C.E., vol. clxxi. (1907–8, Part I), p. 360.

[2] "Munaar Valley Electrical Power Scheme." Minutes of Proceedings Inst. C.E., vol. clxix (1906–7, Part III), p. 367.

Mr. Lacey.

1926–1927 appeared to have been a more critical one, and 1927–28 might have been still more so, as the north-east monsoon rainfall was only 6·2 inches in 1927. The rainfall of the dry-weather period of 1928 was not given. The following Table was an analysis of the actual yields for 1926–27, given on p. 467, in terms of inches on the catchment.

1926 N.E. monsoon.			1927 dry weather.				
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	May.
4·2	2·5	1·4	0·8	0·5	0·3	0·2	0·4

For the full development of the 21,800 HP. a constant supply of 80·5 cusecs would be required (p. 485) from the catchment-basin of 42 square miles, or a yield of 2·143 inches per month of 30 days from the basin. From the Table given above, storage would be required from the end of November to meet that demand, and the storage x inches that would just run out at the end of May would be given by :—

$$6 \times 2{\cdot}143 = x + 3{\cdot}6,$$
$$\text{whence } x = 9{\cdot}258.$$

Supposing the reservoir to be full at the end of November, it would be empty by the end of May. Should there be any delay in the setting-in of the south-west monsoon the supply would fail. That storage of 9·258 inches on the catchment was therefore an absolute minimum. On an area of 42 square miles it represented a storage of about 900 million cubic feet. To provide for evaporation, and for contingencies such as delays in the setting-in of the rains, storage to the capacity of 1000 million cubic feet would be required for the full development of the 21,800 HP. The existing storage-capacity was 84 million cubic feet, which represented 0·86 inch on 42 square miles. Based on the actual yields of the north-east monsoon of 1926 and of the dry-weather flow of 1927, given above, a draw-off of 0·56 inch per month from the basin was allowed before the reservoir would fail at the end of May, 1927, assuming the reservoir full at the end of January, 1927. If no allowance were made for loss from evaporation and other causes, 0·56 inch per month from the catchment-basin represented a flow of about 21 cusecs, so that with the existing storage only about one-quarter of the installed power could be developed.

The Author gave the total cost of the constructional works and the power-station as Rs. 7,320,000 (£549,000, taking Rs. 1 as

Mr. Lacey. equivalent to 1*s.* 6*d.*) which, he stated, was equivalent to Rs. 335 per horsepower. That did not seem correct; the whole 21,800 HP. would not be developed until sufficient storage was provided, and, moreover, the cost of the transmission-lines had to be added. The cost per horsepower actually delivered at the industrial centres should be given. For example, what was the actual cost per horsepower delivered at Coimbatore? Could the Author also give the rate charged per unit supplied? In view of the statement made in the second paragraph of the Paper, had any estimate been made of the cost of developing electric power at each of the various scattered industrial centres by oil or steam plant?

The type of earthen dam of the forebay upper bund followed the principles laid down in 1904 by Mr. A. Hill, C.I.E., Chief Engineer of the Bombay Presidency, who had stated that for a depth of water of 40 to 50 feet the pressure on saturated material became so great that it would flow unless held in place by dry material; for dams retaining more than 40 feet depth of water it would be but ordinary precaution to have at least 20 feet of dry material above the average limit of saturation. For depths of 40 feet of water he recommended that there should be an inner core of selected material 10 feet wide at the top, and that at the maximum water-level of the reservoir the side-slopes should be 1½ to 1. That core should be protected on top and water faces by material not likely to slip when wet, and the slope of the water face should be from 2½ to 3 to 1. The top of the embankment should be 10 feet above the top of the core and 10 to 12 feet wide. The rear of the core should be covered by granular material not affected by water. The rear slope should be 3 or 4 to 1 to keep the clay soil of the hearting from being forced into the drainage of the granular material, and the latter should be arranged like a filter, the fine stuff being against the core and the coarser screened gravel and broken stone on the outside. At the rear toe provision should be made for the escape of water. In that connection attention might be drawn to some remarks of Mr. J. Mitchell Moncrieff on the stability of clay banks.[1]

Mr. Lush. Mr. Arthur Lush observed that Mr. Furkert's very interesting Paper gave an excellent idea of the remarkable geological formation at Arapuni, and of some of the difficulties to which that formation had led. The Author referred, however, chiefly to the formation above river-level, and some of his opening remarks were so concise as to leave room for misunderstanding.

At the dam site, the breccia which formed the foundation was of excellent quality, and of considerable depth, since bores did not

[1] Minutes of Proceedings Inst. C.E., vol. cxcix. (1914–15, Part I), pp. 275–6.

reach the bottom of it. At the power-house site, the formation Mr. Lush. appeared to be very similar to that at the dam site, except that the sides of the gorge were generally less perpendicular, and there were occasional islands, each consisting of a very large rock, in that part of the river channel which was to become the tail-race. A short distance upstream, the river ran between vertical cliffs, which had been rejected as bridge abutments on account of an old fissure which was found at the back of the terrace above the west cliff. The significance of those details became evident later, when the inshore portion of the excavation for the power-house was made. The good rock was proved to be founded upon a bed of the almost unconsolidated vitric tuff, which extended to a great depth. Little or no change was found in it when a bore was put down to a depth of over 200 feet, thus going below sea-level. The total depth of the bed was still unknown. That vitric tuff was capable of carrying a great deal of weight when suitably contained, but, when exposed, it could be readily excavated by tools or by falling water. No doubt it was falling water that had eroded some of the tuff, many centuries before, undermining the good breccia and bringing down large masses of it, which formed islands and boulders that protected the river channel from further erosion.

Just as the erosion at the falls took place in two steps, as described by the Author, so the erosion of Arapuni gorge itself appeared to have occurred in two stages, or to have been produced by two waterfalls, with an intermediate river-level between them about 90 feet above the subsequent level. That intermediate river-level was at the junction of the unbroken rock with the columnar rock above it, and was marked by some water-worn erosions and a small cave. In that cave Mr. Lush had found an undisturbed river-beach, with the remains of some driftwood on it, and part of the skeleton of a moa lying where a flood had left it on a flat-topped rock, some centuries before. Apparently trees had been growing beside the river at its intermediate stage, since some vegetation, including a fairly large tree-trunk, was found buried beneath some of the rock that had been undermined and brought down at the power-house site. One such piece of rock was 60 feet long, and about 30 feet by 30 feet in section. Beneath those rocks was loose pumice that had settled in hollows and channels, which still carried running water, the river having about 5 feet fall in the length of the power-house.

There was no prospect of driving steel sheet-piling through such boulders, and the flow was such as to make cement grouting impracticable until the river was diverted and the flow stopped. The Public Works Department then rejected a proposal to move

Mr. Lush. the site of the turbine-room further inshore, putting the control-room and various electrical auxiliaries at a higher level. With all respect for both of the parties concerned, he still felt that the first essential in planning engineering works should be agreement as to engineering methods to meet adverse or unexpected conditions. Legal conditions should be made the servant and not the master of the situation. In the instance under discussion the Department obtained all its legal rights, and the contractor met his legal losses, which were considerable, but the very protracted delay involved a loss of revenue to the Department of some £3,000 per week, over a long period, which might apparently have been saved by applying remedial measures to the contract itself when the difficulty first arose.

When the dam was completed, the rapid diversion of the river produced erosion, estimated by the Author at 7,000,000 cubic yards. That was far more than the river could carry away, so that the bed built up rapidly at the confluence, reaching its maximum height within about 16 hours. Thereafter the water-level fell slowly, leaving a bar of boulders, sand, and silt on the upstream side of the channel at the confluence. One immediate effect of the diversion was to stop the flow of water past the power-house site, thus permitting cement-grouting of the pumice, where a coffer-dam was required. Later on, a large pump, electrically operated, was installed on the bar, and the river-channel above it was pumped out, thus allowing the cofferdam to be removed and the work completed in the dry. The natural gradient of the channel assisted that method. The original water-level at the power-house site was about El. 158, with a considerable fall to the confluence, where the water-level, after the power-house was in operation, was about El. 137. Thus the absence of " any special difficulty " in completing the power-house foundations was due mainly to the diversion of the river into the overflow-channel.

Both the Author and Professor Hörnell had commented upon the small modulus of elasticity of the rock. He believed that it was that factor which produced a tendency for the rock to crack when excavation or erosion had changed the loading upon it. For instance, a tendency for the centre of a mass of rock to expand might well produce a tendency for the top of the mass to crack, and water entering the crack would help to widen and extend it. Whatever the explanation might be, such cracks had occurred before, without any obvious loss of stability to the rock. For instance, the south or upstream end of the headrace, after being swept clean by the river, showed a large and extensive crack, filled at the top with tightly-packed gravel and stone. On the opposite side of the gorge, near the dam, cracks were covered at the top by soil, but a small stream, which ran during rain, found its way into a test pit, and so by way of an extensive crack to the trial-heading for the diversion-tunnel, about 160 feet below. That caused no anxiety, as it indicated natural drainage for the abutment, on the downstream side of the cut-off trench; but it was an indication of the need for grouting at the site. Joints were intersected at various places in trial drives, but were usually fairly close, if not tight. One joint traversed the dam-site diagonally, and afterwards led water to "the cavity." He had never understood why the grouting of those joints had been deferred, instead of being dealt with under the contract as originally intended. The amount of grout taken by certain cracks, when the Department finally carried out the work, suggested that the cracks were more extensive than had been realized. The bores which would not hold water had no doubt intersected a crack leading to some permeable bed which would probably provide an artesian water-supply further downstream. Possibly, when the river was returned to its old channel through the gorge, a rise of water-level in that bed resulted in the displacement of the nitrogen gas which made its escape through the headrace. Mr. Lush.

The Author remarked that "at the original filling, the dam moved bodily downstream when the pressure came on." The actual movement was very slight, and was due to the elasticity of the rock. The dam had been designed by Mr. Lush to avoid high intensity of pressure on the rock when it was filled. The stress-distribution was thus less favourable when the dam was empty, and the slight movement observed might well be expected to occur as the resultant moved to its almost central position.

It was intended that jet-dispersers should be used to divert excess water from passing over the spillway, so that the protective work at the falls could be carried out while the station was in service. That method appeared to have been favoured by Professor Hörnell, and seemed likely to save a great deal of time, and therefore of revenue, but the Author did not record that the jet-dispersers had ever been brought into use. As it appeared that the protective works in the headrace should have taken much less time to complete than the protective works at the falls, it would be interesting to know what had led to the change of programme.

With regard to the headrace lining and draining-system, it was not clear why a main drain of only 2 feet diameter had been adopted, in place of a drain or gallery large enough for purposes of observation. The porous layer, rather than the flexible lining, seemed to have been the seat of successive troubles in the headrace, and it would appear that separate drains would have been useful for the area between the original banks of the headrace and the new lining.

Mr. Markwick. Mr. A. H. D. MARKWICK was interested in the 11-year cycle governing the level of lake Taupo shown by Mr. Furkert in *Fig. 9* of his Paper (p. 454). Similar variations in the level of lake Victoria Nyanza had been shown by Sir Napier Shaw,[1] who had also dealt at length with the complicated periodicities which appeared to underlie rainfall and climate.

He regretted that Mr. Platts had dealt so briefly with the transmission lines of the Pykara scheme, on which nearly 25 per cent. of the total cost had been spent. Could he state the sizes of conductor for the lines for which costs had been given? Possibly also a brief summary of the main features of the design, such as ground clearances and loadings, could be given. Was it to be understood from p. 495 of the Paper that no extensions to the towers had been used? On similar lines in Great Britain the use of extensions had been found particularly valuable in hilly country, as it permitted towers to be located so as to take full advantage of the ground. He was rather surprised to find that, with so large an average span as 750 feet, no profile-survey had been made on the 66-kilovolt lines. He thought that an accurate profile-survey was not only useful in giving economical tower-location but enabled towers liable to excessive insulator-swing or uplift to be readily detected. Less than ½ per cent. of the total cost of the lines appeared to have been spent on survey and setting-out.

Mr. Meares. Mr. J. W. MEARES observed that, in connection with the investigation of the rainfall and run-off from the Pykara catchment area, Mr. Platts had referred to the empirical method of forecasting devised by the late Mr. G. T. Barlow and successfully used in various parts of India, and had also mentioned "automatically-recording gauges that roughly indicate the intensities" of rainfall. That factor of intensity was beyond doubt of vital importance in all calculations of run-off where tropical intensities occurred, though where the precipitation seldom exceeded a rate of ½ inch per hour, as in most temperate regions, it was perhaps of less moment. He would be interested to know whether the jet type of intensity rain-gauge which he had described,[2] either in its original form or as modified by Mr. J. H. Field, had been used in Mr. Platts' investigation. Properly calibrated, such a gauge could give results as accurate as could be desired in a matter where the shifting of the instrument by a few feet in any direction, horizontal or vertical,

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[1] Napier Shaw, "Manual of Meterology," vol. i, p. 283–4; also vol. ii. London, 1926 (vol. i) and 1928 (vol. ii).

[2] "The Experimental Development of an Automatic Integrating 'Intensity' Rain-Gauge without Clockwork." Inst. C.E. Selected Engineering Paper No. 2. 1923.

altered the readings; and, as described in the Paper referred to, Mr. Meares. such integrating gauges could be left for long periods in places that were inaccessible during the monsoon.

Mr. G. Bransby Williams observed that the Paper on the Mr. Williams. Pykara hydro-electric scheme contained an interesting account of a method of estimating the yield of a catchment, when accurate data regarding the run-off were not available. The description would have been easier to follow if the Paper had been accompanied by a rainfall-map showing the isohyets in the positions finally assumed for the purpose of the computations. If the rain-gauges whose positions were indicated on the lay-out map were those used for the preliminary estimate, the variation in the mean rainfall between places within a few miles of each other and, comparatively speaking, at nearly the same level, was quite remarkable. He had had experience of many mountainous districts where the variation in the rainfall had been very rapid, but none in which it had been comparable with a diminution from over 400 inches to about 50 inches in a distance of 9 miles, on the top of a plateau. It seemed probable that the estimate of the average rainfall on the catchment arrived at from the records of seven stations, only two of which showed a mean of over 100 inches, and only three of which seemed to be actually on the catchment, might be found to be somewhat wide of the mark when the correct figures became available.

There seemed to be remarkable agreement between the estimated ratios of run-off to rainfall shown in Table IV (p. 462) and those which would be obtained from the formula of the Bombay Irrigation Department for "Ghat" catchments, which was:—

$$y = 0{\cdot}85x - 12$$

y denoting the run-off and x the rainfall in inches per annum. Perhaps the Author, in his reply, would say whether that formula had actually been used for the computation or not.

The 45-year record at Pykara had some points of interest. The fluctuations in the south-west monsoon rainfall were surprising. In the driest year the rainfall during that season was only 27 per cent. of the mean monsoon rainfall. In the driest two consecutive seasons it was an average of 45·4 per cent., and in the driest three consecutive seasons, 58 per cent. of the mean. In the Central Provinces, where, on an average, about 92 per cent. of the whole year's rain fell during the south-western monsoon months, he had found that only 2 years' records out of 4,120 were less than 30 per cent. of the mean, and that the chances were 450 to 1 against the rainfall in any given year, at any given station, being less than 35 per cent. of the mean. In Assam, where the intensity of the rainfall in the

Mr. Williams. mountain ranges exceeded that in the Western Ghats, the chances were approximately 1,000 to 1 against the rainfall in any given year at any given station being less than 48 per cent. of the mean.[1] Those figures indicated that the magnitude of the variations at Pykara was altogether unusual.

There was a close agreement between the actual discharge recorded in the highest flood experienced and the figure that would be obtained from his own formula [2] for abnormal floods on " average " catchments in Eastern India,

$$q = \frac{1{,}700}{M^{0 \cdot 333}}$$

q denoting the discharge in cusecs per square mile and M the catchment area in square miles. The Bombay Irrigation Department formula for " fan " catchments was

$$Q = 7{,}000\sqrt{M},$$

Q denoting the discharge in cusecs. That formula, although not suitable for small catchments, agreed with several recorded floods in the Bombay Presidency. If applied to the Pykara catchment it would indicate a possible maximum flood of 45,000 cusecs.

It was to be hoped that the records of the rain-gauges and weirs that had been established since 1929 would be published as soon as they had been obtained for long enough to give comparatively reliable results. The Pykara catchment was situated in a peculiarly interesting area from the point of view of rainfall, because of the effect of the double monsoon, which in Southern India and Ceylon was often of a somewhat erratic character. Moreover, any reliable statistics regarding rainfall and run-off were valuable in India, where they were often difficult to obtain, some authorities appearing reluctant to publish them.

Mr. Furkert. Mr. FURKERT, in reply to the Discussion and Correspondence, observed that the basic principle underlying Professor Hörnell's recommendation was that the country forming the headrace and the ridge between the two Waikato channels (the low-level gorge and the high-level channel used as the headrace) should be maintained in the same condition regarding water-content as that which obtained prior to man's interference. That was to say, no external water should be brought in contact with the ground underlying the headrace, but the water originally arriving in the ground as the resultant effect of rainfall and evaporation should not artificially be materially

[1] G. Bransby Williams, " Rainfall of Assam," Quarterly Journal of the R. Met. Society, vol. 58 (1932), p. 449.

[2] G. Bransby Williams, " The Flow of Water," p. 21. London, 1934.

diminished. He therefore provided for free access of rain and surface-water into the porous layer. In his original proposal no drains had been contemplated, because the impermeable layer and its underlying porous layer were to follow the natural contour of the ground (all material unsatisfactory for foundation having been removed), and the porous layer all along would extend up to the surface, 2 feet above highest river-level. However, while the report was being prepared probings were being taken which disclosed the fact that great quantities of soft material would have to be removed, even if the rock were not actually stripped, and that the width and consequent area of the expensive impermeable and other coverings would be inordinate. To provide for this contingency he recommended :— Mr. Furkert.

> "Where at the sides of the headrace the surface of the rock cannot be laid bare without removal of great masses of soil, retaining-walls may be considered. They should be watertight, and have a watertight connection with the impermeable lining in the bottom of the headrace, and they should be backfilled with earth to the level of the top of the wall."

No pipes were mentioned in that recommendation, but they were clearly to be inferred, under or through the retaining walls and backfilling, to release water which might otherwise be impounded outside the walls, and to allow the rainfall to reach the rock under the headrace.

Unfortunately in that connection a difference of opinion on a matter of fact was met ; all the New Zealand engineers engaged on the work agreed that the suggestion of earthen banks instead of concrete walls had been discussed with Professor Hörnell and Mr. Werner, and not ruled out, before they left New Zealand on the 31st October, 1930. Mr. Furkert's comments on Professor Hörnell's reports, delivered to the Government before Professor Hörnell left New Zealand, referred to those banks. When detail plans were sent to Sweden in April, 1931, for Professor Hörnell's information (the work being then well in hand), he replied by cablegram on the 18th July, and confirmed by a letter which reached New Zealand in September (the banks then within a month of completion), indicating that he had no recollection of the earthen-bank proposal. However, he did not condemn the proposal, "provided suitable material be used and the work be carried out in a proper manner, etc." He did not refer at all to the drains under the banks, but stated that he considered the banks too small. In deference to that criticism the 1-in-10 back slope shown in detail on Fig. 1, Plate 8, had been added. Mr. Furkert agreed that the pipe drains might still be a cause of trouble, Mr. Furkert. but now that the major part of the water formerly reaching them had been diverted and further filter-material had been placed over their inlets, it seemed very unlikely.

With reference to the thickness of the concrete slabs protecting the bituminous layers, perhaps the word "fortunate" should have been used in the Paper (p. 424) instead of "unfortunate," as had Professor Hörnell specified 8 inches, or, as he later recommended, 12 inches, that thickness would have been employed, as no one in New Zealand had been prepared to depart either from the letter or the spirit of his recommendations; but such a thickness would have involved much extra expense both because of extra concrete and because the individual slabs would have been too heavy to be man-handled. It appeared that 3-inch slabs bedded in bitumen, tongued and grooved, and bitumen-grouted after placing, had been and would be adequate. The maximum velocity in flood would be 9 feet per second, and the smooth regular lining would minimize swirls and eddies. No plans or sketches had accompanied Professor Hörnell's report and recommendations. Mr. Hellstrom questioned the statement that when Professor Hörnell's letter recommending 12-inch concrete slabs reached Mr. Furkert on the 22nd September, 1931, it was then too late to alter the thickness from that of 3 inches then being used. Of course, "it was never too late to mend," but the work of manufacturing the blocks had been let by contract and was already well advanced, and the laying had been started. Mr. Hellstrom was under a misapprehension as to the size of the concrete slabs. On the bottom some were made 10 feet by 10 feet (less than one-sixth of the size that he stated), and the rest were 5 feet by 5 feet. The second layer was of 5-foot hexagons. The slabs at the sides were 2-foot hexagons. They were not reinforced, and as they had been handled from the factory to the stacking and curing ground, then on to trucks, and then carried to place and fitted and bedded without any being broken, reinforcement seemed to have been uncalled-for.

Further information on the matters discussed above would be found in the official documents relating thereto.[1]

Regarding estimates and costs, on pp. 531 and 532 would be found an abstract of the cost account, from which it would be seen that the greater part of the difference between estimates and cost was accounted for by the saving on the Falls structure, which had been built by normal methods, in the dry, instead of by rush methods and subject to the risk of inundation and destruction by floods, as had

[1] Mr. Furkert has supplied copies of Professor Hörnell's report and of other official documents and letters; these have been filed for reference with the MSS. of the Paper in the Institution Library.—Sec. Inst. C.E.

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been anticipated when the estimate of £175,000 had been made, without plans or proper survey (the latter being impossible). That estimate had naturally included a very liberal allowance for unforeseeable contingencies. As the work at the Falls could be completed simultaneously with the other remedial measures, there was no reason for delaying it and afterwards working with the possible difficulties of flood-overflow; also, the cost of installing and later removing the jet-dispersers at the ends of the additional penstocks was avoided. The sum, "Between £500,000 and £600,000" was clearly stated in the Paper (p. 425) to include work at the Falls. It also provided for interest during construction and other overheads not included in the various items of work.

Dr. W. L. Lowe-Brown's remarks appeared to show that he considered that the erosive effect of falling water was not understood by Mr. Furkert and his Staff, but Mr. Furkert was personally familiar with every waterfall of any magnitude in New Zealand (ranging up to nearly 2,000 feet), as well as many in other lands, and had examined during and/or since construction every hydraulic work of any consequence built in New Zealand. The enthusiasm for hydro-electric development at the period during which the works had been designed should be recollected, as it had led to expectation of greater utilization of the Waikato waters than eventuated, and thus to far greater volumes passing over the Falls than had been anticipated. Further, the delays of the contractors referred to in the Paper had sent all the river over the Falls for a long period. It should also be remembered that the river was not being diverted over new ground or works of any kind, but that its flow was simply being restored to a channel in which it had been naturally running in past ages. There were many vertical falls and rapids on the Waikato at intervals up to lake Taupo, in not one of which had any retrogression been detected in the 90 years that the river had been under observation. Nevertheless, the possibilities of erosion had been frequently discussed before works started at Arapuni, and later, and a "wait and see" policy had been followed. Had the work been done before the diversion, it was unlikely that its cost would have been less, on account of the enormous amount of recent material which would have had to be excavated (much of it below water-level) to reach the rock in the lower parts, and also of the fact that the shape of the rock face was not favourable to the construction of economical protective work.

No fear was felt that the sides of the gorge at the dam might come together as the water rose in the new lake, as no swelling could take place, in view of the fact that all the rock was already fully charged with water. A sample of rock had been taken from a drive

Mr. Furkert. in the face of a cliff 150 feet above the nearest water and only 6 feet from a surface exposed to the sun nearly all day. The details of tests on that specimen were given below. They showed that the rock in nature contained no space available for taking in more water.

TESTS ON SAMPLES OF VITRIC TUFF FROM CLIFF ON EAST SIDE OF RIVER.

Sample 6—(6 feet in from surface).

Test for air-content :—

Weight of sample as taken from ground . .	149·4 gms.
Sample then placed in water under evacuated bell-jar for 16 hours, followed by 6 hours in water at atmospheric pressure. After drying surface with cloth, weight was . .	149·3 gms.

The following determinations were made :—

Specific gravity of saturated sample . . .	1·93
,, ,, dry mineral matter . .	2·48
Percentage of water determined by drying sample	19·74 per cent. by weight (= 37·8 per cent. by volume).
Percentage of water calculated from specific gravity of moist sample	37·2 per cent. by volume.

These figures indicate that all the pore-space in the specimen was filled with water.

Samples even 1 foot from the surface had been found to be hardly less saturated. Had the general run of the rock been less than fully saturated even to the extent of 25 per cent. of the possible water being absent, the swelling due to that amount of extra absorption would have been negligible. Saturated specimens had been gradually dried and the progressive shrinkage measured (*Fig. 3*). The results showed that absolutely dry rock would expand considerably when wetted, but that rock in a state of nature, even if not absolutely saturated, would on being fully saturated only expand to an infinitesimal extent.

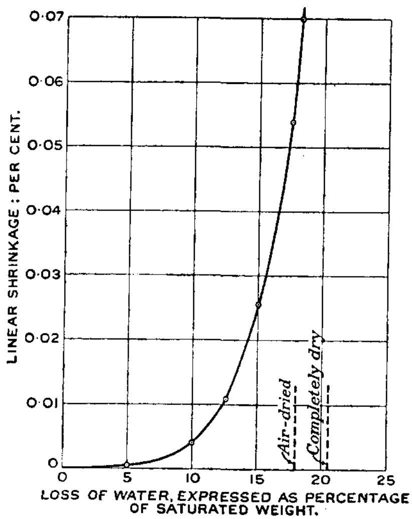
With regard to Mr. Williamson's remarks as to the cost of the remedial works as compared with the value of the installation, the cost of the works for the development of 60,000 kilowatts (the present figure, including primary transmission to the substations which served the various Power Boards, who controlled the distribution) was over £4,000,000, so that the remedial costs were under 10 per cent. The annual output was now over 300 million units, the load-factor 64·28 per cent. equal to 5,631 hours' full capacity per year, and the cost 0·21 penny per unit. When the full installation was in operation that cost would be greatly reduced. The Waikato river with lake Taupo afforded very favourable scope for progressive

Mr. Furkert.

development. One fall of 26 feet (in addition to that of 175 feet at Arapuni) was already developed, and other possibilities ranging from that figure to 500 feet at different parts of the river had been investigated and some of them surveyed in detail. Mr. Williamson's suggested figure of 2,000 million units as a possible output was not over-sanguine. Already the system was returning a profit of over £500 per diem after all charges for generation, primary transmission, interest, depreciation and sinking fund had been allowed for.

Mr. G. P. Anderson's theory of temperature-contraction as the cause of the main crack was worthy of full consideration, but the

Fig. 3.



PROGRESSIVE SHRINKAGE OF SATURATED SPECIMEN OF VITRIC TUFF DURING DRYING.

Paper was not intended to deal with the cause of the crack, which was a subject upon which a special Paper could (and might still) be written.

Mr. Furkert was unable to agree with Mr. Lush's description of the material under the power-house as "almost unconsolidated vitric tuff." It was very different from the columnar rock generally known as vitric tuff, being composed of fragmentary volcanic materials of different kinds thought to have been laid down under water; and the results of the bearing tests, ranging up to, and over, 50 tons per square foot, hardly justified the term "almost unconsolidated." Tunnelling under the river without any lining, to say nothing of untimbered vertical-sided excavations 30 feet deep at the foot of

Mr. Furkert. 4-to-1 batters over 150 feet high, was adequate evidence of the strength of the material. Mr. Lush's positions, first as one of the Government assistant engineers connected with the designs, and afterwards on the Contractors' staff, made his remarks on p. 520 about alterations to the contract and variations to the power-house hard to understand, especially as nothing disclosed during the preliminary period, the Contractors' operations, or the Public Works Department's operations, or since the works were constructed, had indicated that any alteration was necessary or desirable. Had Mr. Furkert's recommendations, made when the Contractors' progress fell far behind contract requirements, been given effect to, the works would have been taken over by the Government long before they were, and much delay would have been saved. At one stage the Contractors had suggested that they should be granted an extension of time for a period of 37 months after the date on which the dam should be filled and the river diverted! Mr. Furkert had estimated 18 months as being ample, and the work actually took 15 months. Though admittedly the diversion of the river had facilitated work at the power-house, the conditions disclosed did not indicate that any special difficulty should have attended its construction simultaneously with that of the dam, as the contracts provided. The movements of the dam downstream when first filled, and upstream when emptied, were much the same as on the second filling, and were mostly due to the elasticity of the rock, though the dam also bent as a cantilever. The reason why the jet-dispersers had not been used was indicated above. They were no longer required when the river was returned to its old bed on the emptying of the lake. The fact that the other works had cost nearly three times as much as the protection of the Falls, and had involved much more difficult work both in labour and imported materials, negatived the suggestion that the Falls work had delayed the final reopening of the station. No delay had occurred, all important works finishing almost simultaneously to schedule.

Mr. Furkert regretted that in the body of the Paper he did not acknowledge the splendid work done by Messrs. W. M. Fisher and J. A. Andrews, Assoc. MM. Inst. C.E., the former of whom had been in charge of the Falls work.

COST ACCOUNT—ARAPUNI REMEDIAL AND RECONSTRUCTION WORKS. Mr. Furkert.

Sectional Description and Total Cost of Each.

Section No.	Description of section.	Total net cost. £	s.	d.
1	Grouting cracks in columnar rock downstream from junction of spillway and intake-structure, also grouting cracks in intake structure itself .	2,788	14	0
2	Drainage-tunnels in lower strata in ridge between gorge, headrace and overflow-channel . . .	2,481	17	4
3	Reinforcement of country at junction of spillway and intake	779	8	0
4	Breaking out and replacing small pieces of reinforced concrete in upper part of penstock intake	40	16	0
5	Concrete block reinforcing acute corner made by spillway and intake-structure	1,274	17	8
6	Cleaning down and guniting whole of penstock intake-structure.	247	17	9
7	*Opening main crack to permit of grouting, drilling* holes, grouting and sealing of open cracks generally with bitumen and concrete . . .	2,608	0	10
8	Lining floor of headrace	42,547	3	2
9	Lining side walls of headrace (including earthen banks)	61,842	9	8
10	Drainage-trench with tunnels to shaft	4,350	3	7
11	Cut-off wall at upstream end of headrace-lining .	3,864	6	1
12	Drainage-galleries near upstream end of headrace	4,648	2	4
13	Drilling holes and grouting country forming eastern abutment of dam	10,237	14	2
14	Drilling holes and grouting country forming western abutment of dam	9,839	19	10
15	Guniting western abutment of dam.	4,005	13	5
16	Bitumen sealing between abutments of dam and country rock	545	7	4
17	Drilling holes and grouting in front of dam . .	2,078	12	5
18	Strengthening of diversion-tunnel	1,531	13	9
19	New control-gates and necessary shafts . . .	36,548	9	2
20	Repairs to original diversion-tunnel gates . . .	1,146	5	9
21	Exploratory bores to follow movement of subsurface water between Arapuni lake and Acacia gully	368	13	6
22	Protection of spillway-channel	39,021	7	11
23	Protection of waterfall	117,138	1	1
24	Backfilling drives south of power-house . . .	264	9	9
25	Inspection of porous-drain system of dam . . .	306	6	0
26	Headrace bridge-piers (strengthening) * . . .	1,174	13	3
	Contingencies: subdivided later into—			
27	Laying up of plant and cleaning up	3,438	3	2
28	Testing and gauging from filling of lake .. .	1,569	7	6
29	Miscellaneous costs accruing from completed remedial measures	3,379	0	10
30	Investigating and sealing leaks in headrace † .	10,148	1	7
	FORWARD . . .	£370,215	16	10

* Decided on after experiences elsewhere during earthquakes in 1929 and in 1931.

† Referred to in Paper as second and third troubles.

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Section No.	Description of section.	Total net cost.		
		£	s.	d.
	BROUGHT FORWARD .	£370,215	16	10
31	Catchwater drain—headrace	264	5	8
32	Additional depreciation on plant (other depreciation charged in various items as work proceeded)	7,356	0	0
33	Head-office administration charges	10,212	18	2
34	Charges and expenses of raising loans	7,756	19	5
35	Interest during construction	14,403	2	3
	GRAND TOTAL .	£410,209	2	4

Unskilled labour, average	1*s.* 6¾*d.* per hour.
Cement	£5 18*s.* 0*d.* to £6 4*s.* 0*d.* per ton.
Reinforcing steel	£12 5*s.* 0*d.* per ton.
Broken stone	13*s.* 3*d.* per cubic yard.
Gravel	5*s.* 6*d.* ,, ,,
Sand	1*s.* 9*d.* ,, ,,

Mr. Platts.

Mr. PLATTS, in reply to the Discussion and Correspondence, observed with reference to the points raised by Mr. Batchelor that 90,000 HP. was calculated on the maximum continuous flow of 165 cusecs that could be developed from the catchment (p. 471) at 50 per cent. load-factor. That figure would be about the ultimate effective capacity of the present development. The continuous drafts given on p. 471 from the different storages had been calculated from reservoir-working Tables, and gave a more accurate estimate of the power that could be developed than the horse-power-year method suggested. The proposed storages given on p. 471 had been fixed tentatively and very conservatively for working out the financial forecast of the ultimate development. Those low figures had been decided on at that time to provide for the contingency of the Pykara plant being the only source of power. Now that the system was being extended by the construction of other plants, it had become possible to develop those storages beyond minimum-water conditions, allowing for an occasional shortage. The Mettur hydro-electric plant was now under construction, and would be operating in 1937; it would be interconnected with Pykara in the first instance at 66 kilovolts via Erode, and subsequently at 110 kilovolts by a direct line to Moyar. Owing to rapid load-growth on the Pykara system, the Mukurthi storage had had to be provided earlier than had been anticipated, and construction of the dam had been begun in 1935. The work was still in progress, and was expected to be completed by the end of 1937. 160 million cubic feet of storage were provided for the dry weather of 1936, of which about 75 per cent. had been actually utilized to make up the average continuous power-draft of 42 cusecs.

400 million cubic feet of storage was being provided for the dry weather of 1937 for an anticipated average continuous power-draft of 50 cusecs. That would be sufficient to meet the needs of the existing plant. The reservoir was designed for a capacity of 1,800 million cubic feet, instead of 1,200 million cubic feet, as shown in the Table on p. 471. The increased storage was due partly to the fact that Pykara was no longer the sole source of power and partly to the fact that subsequent run-off measurements and records from the Mukurthi catchment had shown that the water available was greater than had originally been estimated. 1,800 million cubic feet was the run-off of about the 95-per-cent. minimum year. Mr. Platts.

Isohyetal maps had been prepared departmentally from all reliable existing rainfall-data, as explained at the foot of p. 460, and it was from those that the average monthly rainfalls for the different catchments had been computed. By "Short-term statistics" (p. 465) was meant short periods of record, from 3 to 10 years. Gauging had only been begun in many catchments in about 1924. By "higher and more concentrated rainfalls" was meant the conditions obtaining in catchments subjected to the heavy south-west monsoon, where about three-quarters of the year's precipitation fell in 3 months. With those "higher and more concentrated rainfalls" the loss by evaporation was proportionately less but intrinsically greater. Mr. Batchelor had evidently misread the paragraph, and was comparing catchments with equal rainfalls distributed more or less evenly throughout the year on the one hand and concentrated into a few months on the other. The heading in the Table on p. 470 had been wrongly worded as "90 per cent. of minimum year" in the advance proofs of the Paper and had since been corrected[1] to read "90 per cent. minimum year." The figures given below were the annual runs-off in millions of cubic feet that could be counted on for 90 per cent. of the time, and had been obtained from the duration-curve. The run-off of the minimum year could be counted on for 100 per cent. of the time. The "approximate ratio of unit cost" on p. 470 was the ratio of cost per unit of storage; for instance, storage in the Porthimund reservoir cost about $2\frac{1}{3}$ times as much per million cubic feet as that in the Mukurthi. The Mukurthi reservoir cost Rs.1,270 per million cubic feet of storage. 21,800 HP. was the effective output of the existing plant, comprising two out of the three units. The penstock-capacity was sufficient for that, but the quantity of water during the dry season was not. The stages of growth necessarily had to overlap; for instance, all head-works down to the surge-pipe were designed for the ultimate capacity

[1] See footnote *, p. 470.—SEC. INST. C.E.

Mr. Platts. of the scheme, namely 165 cusecs continuous or 300 cusecs peak discharge. The first storage at Mukurthi now being made would raise the continuous regulated flow from 35 cusecs to about 115 cusecs, which was considerably in excess of the present plant and pipe capacity. An extension of two additional units of 12,500 kilowatts each, served by one new penstock pipe, was to be installed in 1937, and that would again raise the plant and pipe capacity slightly in excess of the regulated continuous flow.

The scheme was already a proved financial success. Power was sold in bulk at 11,000 volts over the whole of the system at the standard tariff regardless of the distance. Power rates had been reduced four times since operation had been begun at the end of 1932, and further reductions would be made as the load increased. The 66-kilovolt transmission-system had now been extended to Negapatam on the east coast, 280 miles away. The load-classification was as follows :—

Textile	56	per cent.
Cement, steel rolling mills, and engineering workshops	15	,,
Town distribution licencees	16	,,
Tea factories	6	,,
Agricultural pumping loads, etc.	7	,,

The average monthly load-factor on the system was remarkably high at 66 per cent. The present peak-load was 12,800 kilowatts, and was rapidly growing.

The gross revenue for 1935–36 was Rs.1,617,350, and the operating expenses, excluding depreciation, Rs.385,730. The return on capital for 1935–36 was 6·9 per cent. The lowest rate for industrial power for a monthly consumption exceeding 300,000 kilowatt-hours was annas 0·35 per kilowatt-hour plus Rs.3 per kilowatt of maximum demand subject to a minimum of 1,000. The rates gradually increased for smaller consumptions and lower load-factors.

The above information also covered most of the points raised by Mr. Lacey, and answers to his further queries were as follows. The capital cost of power per HP. delivered at Coimbatore for the development as actually made to date was Rs.420. In working out the financial forecast for the scheme, the costs of competitive oil and steam generation had been carefully studied, and it was only after making certain that those could be bettered that the scheme had been embarked on. Strong opposition had been met with from the oil and coal interests, and contracts up to 10 years at rates considerably below those then prevailing for those fuels had been offered to industrialists. In spite of that, the Coimbatore mills had rapidly changed over to electric drive, and by April, 1936, after 3 years of operation of the scheme, all the original mills had adopted electricity and the cheap power had attracted ten new ones to the district, every one of which had been electrically equipped from the outset. Mr. Platts.

Referring to Mr. Markwick's remarks, lack of space precluded the inclusion of electrical details, and only broad characteristics and costs could be given. The conductors used on the Pykara–Coimbatore 66/110-kilovolt line were A.C.S.R., 6/·208 aluminium and 7/·069 steel, and those on the Coimbatore–Erode 66-kilovolt line were A.C.S.R. 6/·144 aluminium and 1/·144 steel. The general features of design were similar to those used on the English grid system. Many side extensions had been used for towers on the steep slopes in the hills.

In reply to Mr. Meares, various kinds of rain-gauges had been tried, and those most generally adopted were of the tilting-bucket type with recorder-chart and integrating dial. They had been found to give clear records for up to 8 or 9 inches of rain in a day, but for heavier rainfalls the charts became undecipherable and the dial-readings had to be relied on. That trouble was possibly mainly due to vibration caused by the very high winds which invariably accompanied the heaviest monsoon rains in those hills. The clocks and charts used were mostly fortnightly, and the one at the head of the Mukurthi valley had on three occasions registered over 80 inches in the 2 weeks.

With reference to Mr. Bransby Williams's remarks, the runs-off given in Table IV were the totals for the various months calculated by the method derived from *Fig. 3*, p. 466. As explained on p. 469, the runs-off from the various catchments had been measured for the past 6 years and a sufficient number of rain-gauges installed in the Mukurthi, Sandynalla and Thalipuzha basins to measure the average rainfall over them with reasonable accuracy. The results to 1935 showed that the rainfall in the Mukurthi and Porthimund basins was actually considerably higher than had been estimated, whereas in the other catchments the estimates had been about right. The measured runs-off both for Mukurthi and for the whole Pykara basin were also 10 to 15 per cent. higher than had been computed. Owing to those increases, the flood-discharge coefficients as given on p. 472 had been recalculated and the Mukurthi dam had been designed for a maximum flood-discharge of 13,600 cusecs, based on a coefficient of 3,000 instead of 10,000 cusecs as contemplated before.

Referring to Mr. B. D. Richards' interesting remarks, the following Table (p. 536) gave the extended rainfall and run-off statistics for the Thalipuzha and Sandynalla catchments up to 1935. They should be read in continuation of the Tables given on p. 465. The rainfalls up to 1932 were computed from only two or three rain-gauges in or near the

Mr. Platts. catchments, and the run-off measuring apparatus was not very accurate. From 1932 onwards, the Thalipuzha rainfall had been measured by nine gauges distributed over the catchment of 6·7 square miles, and the Sandynalla rainfall by six gauges. The runs-off had also been measured accurately by the newly-constructed V-notch weirs.

Years.	Average rainfall: inches.	Measured run-off: inches.	Run-off: per cent.	Run-off differences: inches.
Thalipuzha Basin.				
1928–29 .	228·0	180·5	79	47
1929–30 .	297·8	238·5	80	59
1930–31 .	217·9	176·7	81	41
1931–32 .	317·2	275·8	87	42
1932–33 .		Records incomplete.		
1933–34 .	312·5	275·0	88	37
1934–35 .	168·1	136·7	81	31
1935–36 .	195·3	156·8	80	39
Sandynalla Basin.				
1928–29 .	39·4	14·5	37	24·9
1929–30 .	46·7	17·3	37	29·4
1930–31 .	73·5	—	No record.	—
1931–32 .	42·9	14·9	35	28·0
1932–33 .	56·8	25·2	44	31·6
1933–34 .	67·2	30·4	45	36·8
1934–35 .	39·0	11·2	29	27·8
1936–36 .	46·7	10·5	23	36·2

With regard to evaporation-loss measurements, the figures given on p. 471, which were the average of 3 years, had since been extended to 6 years and showed no material difference. 4½ feet might therefore be taken as established for the particular climate and elevation of 6,500 feet. Until 1934, the evaporation had been measured on the Glen Morgan reservoir. For convenience the apparatus had then been moved to the forebay, and the readings had since been taken there.

Referring to Mr. Williamson's comments on the costs, the total of Rs.7,320,000 given on p. 494 was inclusive of all the incidental charges for the works mentioned. General headquarters charges and expenses included design, direction, inspection and testing of plant before shipment, etc. As most of the area occupied by the works was reserved forest, land-compensation was very small. The estimated cost of the additional penstock-pipe and two 12,500-kilowatt units which were to be installed in 1937 was Rs.3,750,000. The estimated cost to completion of the Mukurthi dam and connected works, which would provide water for very nearly the full capacity of the above plant, was Rs.2,250,000, making a total cost for the complete extension of Rs.6,000,000. That worked out to Rs.240, or about £18 per kilowatt.