Paper No. 6102

**Recent developments in Nile control†
and**

Paper No. 6370

**An analytical study of the storage losses in the
Nile Basin, with special reference to Aswan Dam Reservoir
and the High Dam Reservoir (Sadd-el-Aali)†****By****Abdel Aziz Ahmed, D.Sc., Ph.D., M.I.C.E., M.I.E.E.**

Discussion

The Chairman (Sir Herbert Manzoni, President of the Institution) said that Dr Ahmed had prepared his two Papers some years ago, but circumstances had been such that they could not be given at that time.

274. He knew almost nothing about the subject of the Papers, on which the Author and many of those present were experts. When reading the Papers he had found himself quite out of his depth in the technical arguments, but he had easily been able to recognize the courage that the Author had shown in challenging opinions which had been expressed and theories which had been propounded over a great number of years by men whom he would certainly recognize as experts. That was the sort of Paper which ought to be presented to the Institution. Whether the Author was right or wrong he was at least saying something new, something which, presumably, had not been said before at a meeting of the Institution, and something which, if said anywhere, should be said in the lecture theatre of the Institution, the home of civil engineering.

275. In writing the Papers and presenting them for discussion, the Author was doing the very thing for which the Institution existed, much more than it existed for the description of works which had been carried out. It was courageous to get up in the lecture theatre of the Institution and say "This is wrong" and "That has been forgotten", and that something else should have been done, but, if the President judged aright, the Author was accustomed to showing that courage. That was how the two Papers had impressed the President, who was not able to judge them from the technical standpoint, which so many of the members present could apply and which no doubt they would apply in the discussion which followed. It had been fascinating to listen to the presentation of the Papers and it had been well worth while for the Institution, that the Author had come all the way from Egypt to present them.

Dr H. E. Hurst (Scientific Consultant to the Ministry of Public Works, Egypt), before commenting on the Author's proposal in his first Paper for reducing losses in the Sudd Region by pumping at the tail end of the swamps, referred to the accepted scheme of a diversion channel. The channel, which was shown in Fig. 8, would leave the Bahr el Jebel above where the main losses occurred, carry about half the discharge, and leave the remainder to flow down the present channel at a level at which only normal transit losses would occur. That scheme required a barrage across the river, with headworks for the diversion channel, some improvement of the main river channel above the headworks, and of a side channel which would be the beginning of the diversion. Studies

† Proc. Instn civ. Engrs, vol. 17, pp. 137-200 (Oct. 1960).

of the Sudd Region had begun 55 years ago with the object of preventing losses either by embanking the river or by means of a diversion channel. During that time many engineers, British and Egyptian, under British and Egyptian Inspectors-General, had worked on the problem. Of those, E. S. Waller and H. G. Bambridge had worked on the Upper Nile for 30 years, and thus were responsible for much of the data on which the final project was based. The general consensus of opinion had always been in favour of a diversion project, and the present scheme was put forward by the late A. D. D. Butcher in 1938, and finally adopted by the Egyptian Government in 1946, after a general revision of Nile Conservation projects had been made¹. To study the effect of the scheme on the life of the people of the Southern Sudan, the Sudan Government had appointed the Jonglei Team, which consisted of engineers, surveyors, a political officer, and experts on agriculture and veterinary matters, who had worked in the region affected from 1948 to 1953 and had produced an excellent and very comprehensive report^{33*}, which for many years to come would be indispensable to anybody concerned with affairs in the Southern Sudan.

277. The Author's scheme required a dam at the Bedden Rapids to produce power, 670 km of transmission line, and two pumping stations requiring a total of 80 MW, with dredging and embanking 220 km of the Bahr el Jebel up to Hillet Nuer. One pumping station was to be at Lake No at the tails of the Bahr el Jebel and Bahr el Ghazal. Taking the Jebel first, the proposal for that was to straighten and embank the river as far as Hillet Nuer, 220 km from its tail, and with the aid of the pumps to increase the slope from its present average of about 3.7 cm/km to 5 cm/km, which was about the same as the slope at Hillet Nuer. That would be done by lowering the level by 3.4 m at Lake No. According to the Author that would create a stream of a steady slope of 5 cm/km and would not only prevent losses below Hillet Nuer, but would drain the swamps up above. The average loss below Hillet Nuer was $1\frac{1}{2}$ mld out of a total of 14 mld between Mongalla and the White Nile at the Zeraf mouth.

278. The effect of pumping, however, would be to produce not a steady slope but a drop-down curve, which could be calculated for a rectangular channel of the same bed-slope and dimensions as the Bahr el Jebel, and would be an approximation to what would actually happen. The results of the computation were shown in Fig. 14, which showed how quickly the effect of pumping disappeared as the distance from the pumps increased. The drop was reduced to half after 11 km, and was only 20 cm at 100 km. Those figures were approximations but were clear evidence, if any were needed, that the effect of the pump died out in a very short distance. Its effect for 70 km below Hillet Nuer would hardly be measurable. A discovery which had a very important bearing on swamp reclamation schemes had been made by the Egyptian Irrigation Service in the course of investigations on the Bahr el Jebel. Many measurements showed a steep downward slope of the water-surface in the swamps from the river outwards, which fell off rapidly with the distance. On one line, a little distance above Hillet Nuer, where gauges were established, there was a fall of 60 cm in 400 m³⁴. Steep gradients had also been observed by Hawes in the swamps of Lake Kioga. Those gradients were due to the resistance to flow caused by the vegetation.

279. The inference from the present discussion was that the effect of pumping from an unbanked channel through swamps would extend for only a short distance up the channel and for a very short distance on either side. The embanked channel to Hillet Nuer, as designed by Butcher, was estimated to save 1 out of $1\frac{1}{2}$ mld loss, and it was clear that the pump would not add to that gain.

280. The most important principle to be followed in preventing losses in the Sudd Region was to stop water spilling into the swamps, which could be done either by embanking the channels, or by providing a diversion so as to lower the level in the existing channel below the top of the banks and, in addition, closing any spill channels.

281. With regard to the Bahr el Zeraf the losses for 200 km up from its mouth were

* References 33-62 are listed on p. 414-5.

small and were not more than ordinary transit losses. Losses in swamp occurred above Khor Gurr which entered the Zeraf at 240 km from the confluence of the Zeraf and White Nile. Calculations of the drop-down curve for a channel of rectangular section of the same depth and slope as the Zeraf showed similar results to those for the Bahr el Jebel, and were indicated in Fig. 14. No calculations were needed, however, to show the futility of installing a pump on a channel to prevent losses which only began to occur 150 miles away.

282. The reclamation of the Bahr el Ghazal was a problem of a different kind from that presented by the Bahr el Jebel. The Bahr el Jebel and its swamps had been studied in great detail over a period of 50 years. There had been no similar study of the Bahr el Ghazal, and little was known about its hydrology except the discharges of the principal tributaries from 1942 onwards, which were quoted in § 161. Those tributaries were all torrential and were formed by many streams which rose near the Nile-Congo watershed, and flowed through undulating rather than hilly country, down to the flat plain where all but the Jur lost themselves in swamps. They were practically dry from December to May, and that was also the time when the Blue Nile and its tributaries were

FIG. 14.—DROP-DOWN CURVES

low, so that the supply would have to be supplemented by stored water. Any rectification of channels to prevent losses would produce nothing during the time of shortage and extra (untimely) water during the flood season which, unless it could be stored, would be useless or even dangerous. Annual storage reservoirs could store that excess, but to make full use of it, and to deal with the low years, long-term storage would be required. It was probable that suitable sites for annual storage reservoirs could be found on the upper courses of some of the tributaries, though they had not been examined. The two largest tributaries, the Jur and the Lol, were formed by streams which combined below the country in which there were likely reservoir sites, so that to control them five annual storage dams might be necessary. Whether there were any sites suitable for long-term storage was not known. In spite of the Author's remarks on the theory of long-term storage, the amount of storage at present thought to be obtainable was not enough to utilize fully the Nile discharge in many selections of years which had a greater probability of occurrence than the last 60 years.

283. Before a serious project for reclamation of even a part of the Bahr el Ghazal swamps could be made a great deal of work would need to be carried out, mapping, levelling, sounding water depths, obtaining information about the people and their mode

of life, their numbers and the numbers of their cattle, the effects of any project on grazing and fisheries, exactly as was done for the Bahr el Jebel. From what had been already said, the Author's pumping scheme could do little to prevent losses in the Bahr el Ghazal basin and the actual prevention would have to be either by providing a diversion channel, or by means of embanked channels through the swamps. On account of the small slopes below Ghabat el Arab either alternative presented formidable difficulties.

284. The objections to a proposed diversion scheme (§ 159) which the Author had made, that maintenance of banks would entail very heavy running expenses, would apply in a much greater degree to embanking channels through the Bahr el Ghazal swamps. It was possible that when full information became available, on which to base a reclamation project for the Bahr el Ghazal, the cost, which was bound to be heavy, might be prohibitive.

285. Summing up, Dr Hurst said that of the Author's complicated and costly scheme, only the embanking of the lower parts of the Bahr el Jebel and Bahr el Ghazal made even a small reduction of the losses in the Sudd Region. The dam and hydro-electric station at Bedden, the long transmission line, and the two pumping stations contributed nothing.

286. Dr Hurst said that the losses and gains described in the second Paper were the differences between discharges at Wadi Halfa and Aswan, measured or estimated, and the data used were those published in the volumes of "The Nile Basin"³⁵. The reality of the losses depended on the accuracy of the discharge measurements, since the errors of both measurements were contained in their difference. The accuracy of discharges had been discussed in "The Nile Basin", and also in a Paper to the Institution⁹ by Dr Hurst. Errors consisted of two parts, an accidental part which could be decreased by making a number of measurements, and a systematic part which could not be decreased by repetitions. On ordinary sites with good observers the probable error, which applied only to the accidental part, was usually estimated in the Nile Basin statistics as about 5% for a single measurement. In the case of the sluice discharges the probable error of the low stage discharge was estimated as 0.6%, and in flood time 1%. Where levels had been recorded, but there were no measurements of discharge, approximate discharges could be found by the use of a gauge-discharge relation determined from measurements made at some other time. Owing to changes of river-bed, however, those approximate estimates were liable to considerable errors^{36,37} which could amount to as much as 5 mld in a year, when the year was one of those in the series from which the curve was made, and to an unknown amount for a year outside the period. Differences of ± 8 mld between estimates of the discharge of a year at Halfa and Aswan, therefore, could be entirely due to departures from gauge-discharge curves made for an entirely different period, and were not evidence of real losses or gains. Measurements of a good standard of accuracy had begun at Aswan with the sluice discharges in 1903³⁸, and at Halfa with current-meter discharges in 1921. No reliable deductions about losses or gains could be made before 1921. The absurdity of such deductions could be seen in the years 1916-18 (Fig. 10). 1916 and 1917 were years of high floods. The first had produced a supposed gain of 4 mld, the second neither gain nor loss, and 1918, a low flood of short duration, a loss of 8 mld.

287. The years 1890-92 had been years of supposed large gains (average 7 mld), 1890 and 1892 had been very high years, and 1891 had been above the average. As an example the distribution of the average gain month by month had been calculated and the astonishing result was shown along with Halfa gauge in Fig. 15. It would be seen that while the river was falling there were no gains, but only losses. As soon as the river began to rise the gains began, and continued up to and during the peak of the flood. The rise of the river in 3 months was $7\frac{1}{2}$ m (25 ft) and during that time there was a gain of $11\frac{1}{2}$ mld, twice the contents of the present reservoir, and there was a further gain of 2 mld in the highest month. That was the inverse of what would happen on the accepted theory of the movement of underground water, and the result could not be

explained on any rational hydrodynamical theory. The regular annual rise and fall of a river flowing through a permeable medium produced an annual rise and fall of the underground water level in the adjoining medium, whose amplitude fell off exponentially with distance from the river, and whose maxima and minima lagged behind those of the river, with a lag increasing with the distance. Consequently, with a rising river the slope away from the river was downwards and the flow consequently outwards, while on the falling river it was reversed. There was therefore a zone which filled and emptied annually, whose volume depended on the permeability of the material; the smaller the permeability the smaller the zone.

288. From 1921 to 1952 the differences were much less, and that was clearly due to

FIG. 15.—LARGE APPARENT GAINS, 1890-92

the fact that they depended on actual measurements both at Halfa and at Aswan. The differences in that period had been analysed for the months when the reservoir was in use. After the first heightening the reservoir usually began to fill in November, and after the second, usually in October, and was always empty by the end of July. Sometimes the reservoir had been partially filled before October in order to lower the peaks of high floods, and those years had been omitted. During the period when the reservoir was in use the reservoir levels at the dam ranged from about 2 m above the level of an ordinary flood to 16 m above after the first heightening, and to 24 m above after the second heightening. The average range of the unregulated river was about 7 m. The levels in the reservoir when in use were therefore much higher than flood levels and the surface areas greater, so that losses should also be greater. The errors of measured discharges, also, were then less than in flood time. The mean difference for 24 years in the period 1921-52 between the discharges at the head and tail of the reservoir was 0.49 mld a year. To that must be applied a correction of -0.19 to reduce current meter

discharges in October to sluice discharges, and a correction of +0.18 to allow for the fact that the natural river during the working season had fallen 1 m on the average and so had contributed water besides that directly entering at Halfa. The net result was an average loss of 0.5 mld. The mean annual loss from evaporation on the present reservoir after the second heightening was between 0.5 and 0.6 mld. Thus, the losses computed from measured discharges and from evaporation were practically the same. The probable error of the mean difference was ± 0.1 mld, apart from systematic errors which it had been attempted to eliminate. Another calculation had been made for the interval of 1 month during which the present heightened reservoir had been held at full supply level before emptying began. The average loss in 9 years had been about 60 millions on a discharge of about 3,600 million. The loss due to evaporation was between 50 and 60 millions. The conclusion, therefore, in both cases was that there was no significant difference between losses calculated from discharges and from evaporation, and that the average gains and losses referred to in the Paper were imaginary.

289. Having analysed the fundamental data on seepage losses, the following were some general remarks on the water underlying the deserts through which the Nile had cut its channel. Ball²², Hellstrom²³, and Murray²⁴ had given practically all the available information. The Author had given some of it in his Paper, but had omitted the most important of all, which was emphasized by Murray and Hellstrom, and that was the very slow rate at which water percolated through sandstone.

290. The basis of underground flow theory was Darcy's experimental law, which said that the discharge Q through an area A at right angles to the flow was:

$$Q = cAi$$

where i was the hydraulic gradient and c was called the coefficient of permeability of the rock. Hellstrom had measured c for a sample of Nubian sandstone, and had also estimated it from observations on wells in Dakhla Oasis. He had further given results of measurements on sandstones in America and Sweden, both laboratory tests and measurements by means of wells and of a mine. The approximate values for c were given in Table 16.

TABLE 16

	c : metres per second
Sand from dunes in Holland	2.10^{-4}
Fine sand, Sweden (80% of particles between 0.2 and 0.4 mm dia.)	$3.5.10^{-4}$
Sandstone and slate at Helsingborg:	
(a) flow in horizontal direction estimated from observations in a mine	4.10^{-7}
(b) flow in vertical direction estimated by infiltration of rainfall	4.10^{-9}
(c) laboratory test on solid specimen of sandstone without fissures	$1.4.10^{-5}$
Sandstone at Mingechaur (Transcaucasia):	
(a) from observations in wells	7.10^{-7} to 1.10^{-5}
(b) laboratory tests on solid specimen without fissures containing gypsum	8.10^{-8}
Nubian sandstone:	
(a) laboratory tests on solid specimen without fissures	$7.7.10^{-5}$
(b) estimated for Dakhla Oasis (from wells)	$2.4.10^{-5}$ to $2.4.10^{-4}$

He had also quoted an investigation of the Great Artesian Basin of Australia where the velocity of the artesian water in sandstone was estimated at 1.65 ft per annum. The velocity through sandstone varied from 8.10^{-8} to $2.4.10^{-4}$, omitting the case of vertical flow. The Nubian sandstone appeared to be more permeable than the other specimens.

291. On those figures, Hellstrom had calculated the velocity of the water through the sandstone under a gradient of 1:2000 as about 15 m a year, and at that rate he stated that the water would take 100,000 years to travel from the intake beds to the Qattara depression near the Mediterranean Sea. The water now reaching the Nile and the Egyptian Oases fell in geological times, and Murray had aptly called it "fossil water". The very small velocity of percolation meant that the annual wave, caused formerly by the rise and fall of the Nile, and now by the filling and emptying of the reservoir, would fall off in amplitude very rapidly, so that the distance over which it had any practical effect was a matter of hundreds of metres rather than of kilometres.

292. The concluding section of the Paper was an estimate of the losses in the High Aswan Dam. It was stated (§ 260) that evaporation losses on the Aswan and the High Dam Reservoirs had been computed from observations taken on a Piché evaporimeter multiplied by a reduction factor of 0.5. The Author condemned that but had omitted what was also written in the source from which he had quoted²¹ that the factor was taken from observations over a number of years with tanks floating in the river at Wadi Halfa (0.54), Aswan Reservoir (0.45), and Giza (0.63), and 0.5 was adopted as a round figure. It was also said that it seemed reasonable to suppose that the evaporation from a large open surface was a little less than that from the largest tanks used in the experiments. The Author had then taken 10 mld as the annual loss by evaporation on the High Aswan Reservoir, which, however, was the loss at the top level of the reservoir, which would only be reached in very high floods. The average loss as calculated from trial regulations was about 7 mld.

293. In conclusion, with regard to the High Dam, all the evidence showed that seepage was likely to be negligible and that evaporation losses would be at the same rate as on the present reservoir. It could seldom have been the case in projecting a large reservoir that there had been the advantage of a preliminary experiment of the size of the present Aswan Reservoir.

Mr R. H. MacDonald (Partner, Sir Murdoch MacDonald and Partners) asked how the project for the High Aswan Dam had come into being. He remembered that in 1928 an Egyptian engineer had said to him: "We are going to heighten the Aswan Dam by 7 m, but that is all wrong; it should be much higher, to level out the whole flood." It might be true to say that the idea originated in 1928, but so far as he knew it was only after the 1939-45 war that the idea of a really high dam had come into being. He understood that the original schemes had been for a much higher dam even than that now proposed; he recalled a scheme by Dr Gallioli for impounding 6,000 sq. km of reservoir area, but that had now been reduced to 4,000 sq. km.

295. Those post-war schemes had been originally proposed not so much to benefit the irrigation of Egypt but for the impressive amount of power which it had been supposed that they would produce and which by that time the Egyptian economy would accept. In the old days there had been no way of utilizing the power which could be produced. In fairness to Mr MacDonald's predecessors who had been concerned with dams in Egypt, it should be said that they had never thought of anything like the High Aswan Dam because in their day it would not have been possible to obtain the enormous sums of money which foreign aid, etc., had made available. Today it was possible to borrow £200 million for a scheme and nobody asked about repayment. A great effort would certainly be made, in spite of what the Author had said, to carry out the High Aswan Dam project, mainly from the point of view of power and not of irrigation.

296. The original proposals might not have been put forward if the proposers had thought that the site for the new dam would be covered by 200 m of overburden before getting to rock. They had thought that the new dam would be on the same granite shelf as the present Aswan Dam. In 1953, when the facts had been ascertained, no other site could be found, and those concerned had been so committed that they had to go on with the site chosen.

297. The Author had made a very sound theoretical case for the use of the Great

Equatorial Lakes and for the use of other sites for storage reservoirs other than Aswan, but perhaps if foreign aid was forthcoming it would be possible to undertake all those schemes, each complementary to the others. It depended entirely on how much money was available.

298. In his account of the different ways of producing variations in the flow from a 70-year record the Author had done a very good job, but Morrice had shown³⁹ how electronic computers could be used to do that work. A good deal of probability theory could be avoided by putting the data through an electronic computer, so that any desired result could be obtained.

299. The Author had given details of accretions in the river from Wadi Halfa to Aswan. When Herodotus, who lived about 500 B.C., went up the Nile to Aswan he had been told that the Nile did not come from the far Sudan but from a few miles farther south. The Author's figures for accretions seemed to show that about half the river came from them. It would be pleasant to be able to believe Herodotus, and the Author was in good company; but why were these accretions supposed to occur in high flood and not when the river was low? Would the Author re-examine his theory?

300. The Author was probably right about seepage; there was bound to be seepage from a reservoir of 4,000 sq. km, but it would probably not be so big as the Author thought. Mr MacDonald's firm was concerned with a dam in Pakistan in rather similar country, built by the Irrigation Department in 1958. It was yielding about half the quantity of water which had been expected, so that there was obviously some heavy seepage going on. On the analogy of that dam the seepage at Aswan would probably work out at 22 mld cu. m, but all these questions of seepage depended on the geology, and he did not know whether anyone knew the geology of the area well enough. It was not a hypothetical question, and seepage would have to be considered. If it were not for the provision of power at the High Dam it would definitely be much better to store all over-year water in the Equatorial Lakes, where the rainfall was constant and evaporation did not come into the picture. He hoped that the Author would get his way and that all the other schemes he proposed for the Nile would be adopted at some time or other.

Mr Gerald Lacey (Consultant, Sir Murdoch MacDonald and Partners) referred to three subjects in the Paper which had a bearing on the High Dam: the first was siltation, the silting of the dam; the second was percolation, and the third evaporation. It was undeniable that one result of the construction of the High Dam would be that a great quantity of silt would be trapped in it, but with over-year storage and the eventual use of nearly all the water in the river, the quota of silt could not always be kept flowing as an irrigation adjunct, and some of it must inevitably be trapped. It was some comfort, however, that a great deal of water *and* silt, which at present flowed unutilized to the sea whenever high floods occurred, would, in future, be trapped. There was a great deal of argument about how useful that silt could be. If it was as valuable as some people thought, it might eventually be possible even to dredge it or remove it from the reservoir in one way or another and put it where it was wanted. That might seem rather a Heath Robinson idea, but there had been one or two fanciful suggestions in connexion with work in Egypt in the past, and indeed the Author had described the High Dam project itself as a fantasy.

302. On the question of seepage, the Author had made a special point of the fact that no allowance had been made for seepage in the High Aswan Dam. Mr Lacey was familiar with the Wadi Rayan project, and one of the things that had held it up was the great doubt felt about whether the Wadi Rayan would hold water. The geological formation of the Wadi Rayan was such that it raised more doubts than those which might arise about the High Aswan Dam. Sir Cyril Fox, the geologist, had eventually concluded that there was no great risk of high seepage losses in the Wadi Rayan project. The Author held the same view and expected that in time the silt would seal any fissures and thus prevent heavy losses. It was most unfortunate that the late Sir Cyril Fox had not been asked, at the time when he reported on the Wadi Rayan, to

report also on the possible losses from a high Aswan dam, where the geological formation was somewhat different. So far as seepage losses were concerned it was possible, and indeed probable, that they would be somewhat greater than expected, but Mr Lacey did not think that if they amounted to an additional 2 mld cu. m a year it would seriously upset the agreement recently reached between the Sudan and Egyptian Governments on the sharing of the water. He had no doubt that they could come to an amicable arrangement about that.

303. On the subject of evaporation, the Author had stated that the water surface of the reservoir made by the High Aswan Dam would be 4,000 sq. km and that the losses were estimated at 10 mld cu. m. That corresponded to an annual loss in evaporation plus seepage (if there was any) of $2\frac{1}{2}$ m/year. In Iraq, where it was very hot, the evaporation was of the order of 1 m 80 cm/year. That was an average of about 5 mm/day.

304. The Author had referred to the difference in evaporation at different elevations, and in § 265 had used a log. equation to find an increase in wind velocity of 56% in rising from 10 m to 100 m. He had used another equation to find how that velocity affected the evaporation and had concluded that for this High Dam at 100 m the evaporation would be 40% greater than at 10 m. Mr Lacey was unable to accept the Author's contention that the evaporation losses would be increased owing to the elevation of the water surface of the reservoir. The vast sheet of water, extending for many kilometres, replaced the Author's plane of reference in the equations which he had employed, and vitiated the arguments which he had put forward to show that the evaporation losses had been under-estimated.

Mr C. G. Hawes (Consultant) said he had been associated with the Nile for a number of years, though mostly in the upper reaches. Having been in Devonshire for the last 8 or 9 months and abroad for the 3 years before that, he did not know what the exact position was with regard to the sharing of the waters of the Nile, apart from the statement in the Paper that the Sudan was to get 16 mld cu. m, but he had some comments to make on the storage which seemed to be required at the High Dam. He assumed that the question of the High Dam had been settled and could not be altered. The design capacity was 130 mld cu. m, of which 30 mld was for the storing of silt, 70 mld for the control of the water, and 30 mld for contingencies, for dealing with floods. In various places where he had worked, including the equatorial lakes, he had found it very useful to make a behaviour trial of the storage, or proposed storage, to see what would happen if the conditions which it was intended to impose were applied over the length of the period for which data were available.

306. In making those trials on the Nile, he had done one from 1870 up to 1953–54 and three others from 1898–99 up to 1953–54. He had divided the waters of the Nile between the Sudan and Egypt, giving the Sudan 21 mld cu. m and Egypt 63 mld cu. m out of a total of 84 mld cu. m. The Sudan might not have been very pleased about that, but this had been only an exercise for his own satisfaction. He had had to do another trial with 20 and 60 mld cu. m respectively, because he had found that the river would not sustain by itself, with the natural discharge, a draught of 84 mld cu. m without going short in some years. For the tests the natural river was taken, the Sudan's share deducted, and the balance carried forward. The Egyptian share was then deducted and any minus or plus figures debited or credited to storage. From that the losses were deducted, and finally a figure was obtained of the progressive storage which was required to control the river properly.

307. The first test had started in 1870. In the period from 1870 to 1898–99 a great deal of water had been wasted to the sea. For the period following that there had been no water at all wasted to sea. The dam had filled to 130 mld cu. m and had gradually reduced, having started off at the critical period with an appreciable quantity in hand. For the period 1900–1953 alone he had found that the maximum storage built up was 81 mld cu. m to control the river to give a draught of 84 mld cu. m/year. He had allowed

5 mld cu. m/year at Aswan to come from the Equatorial Lakes. The Author had mentioned a figure for storage of $8\frac{1}{2}$ mld, but that did not make any allowance for silting. On that question, since the water was going to be divided between the Sudan and Egypt, he suggested that some of the silt would be put down in the Sudan reservoirs, so that 30 mld cu. m would not be necessary in Egypt, and he took a figure of 20 mld. That gave 100 mld cu. m as the necessary storage at Aswan to take care of future higher discharges in the river.

308. He preferred to plot the discharge records on double probability paper. He had done that for Lake Victoria with the yearly run-off and extended the graph to cope with a 500- or 200-year run-off. If that were done with the Aswan figures—and it had been done; he had seen work on it—it would be possible to get a figure for discharge in the river which could be put into the existing data to repeat the tests so as to get the storage which would be provided to take care of future conditions. It would, however, be noted that his figure of 100 mld agreed with the figure given by Dr Hurst of $70 + 30$ mld. Mr Hawes had found that the river would not sustain 84 mld cu. m by itself unless the equatorial project quantities were brought in.

309. On the question of silt and losses by percolation, he thought that there would be losses by percolation. He knew of one case, in Chile, where half the expected discharge into a hydro-electric station had been lost; it had gone into the rock formations, which were all volcanic, and had disappeared, coming out in the river-bed downstream of the power station. With all the Nile silt held in the reservoir, and all the very fine material put down on its bed, if there were any appreciable losses they would soon be stopped by silting up. He had had an experience in India in emptying a reservoir near Poona which held about 5,000 million cu. ft. They had started with a head of 40 ft on the sluices and emptied the reservoir and had the river running through the dam quite freely. That had been at the beginning of the monsoon, and he had been able to go round the bed of the reservoir and examine it. The scouring sluices, which were supposed to scour the reservoir, had not scoured anything except the river channel. The material put down on the whole of the cross-section, and all the way up to the head of the reservoir had not been moved at all. An interesting point was that some of the sluices were outside the river-bed and consequently not subject to flow axially, and in front of those the deposited silt had been scoured away in a very small zone only. The under-sluices which used to be provided for scouring a reservoir thus were of no use at all, and at Aswan, where all the silt in the Nile must be stored, the reservoir must silt up.

310. The scheme for the Wadi Rayan which the Author had suggested, was very interesting, but Mr Hawes did not think it would produce lower losses than the water stored at Aswan. It would also involve the use of power to get the water back into the river, though the power would be very cheap.

Mr Herbert Addison (Consultant) commented on the question of seepage. Since the Author's figures were so startling they would bear further examination. If the leakage from the reservoir should indeed be on such a large scale as the Author had suggested, what would happen to this water? Perhaps it would take cover underground in the way suggested, but at any rate it might show better judgement than the water that evaporated annually from the reservoir surface and would never be seen again. Was it possible to be so sure, however, that the seepage water had gone for good? At least it was assured a hiding place deep beneath the ground, where neither sun nor wind could get at it, but it had not vanished; it was still there.

312. Could not an attempt be made to predict its future movement? There was a very useful guide in Fig. 13 which represented the Libyan water-table, and on it lines of equal water-table level were shown. Since the direction of water flow beneath the ground was everywhere at right-angles to these lines, over large areas of country the flow was directed towards the River Nile. Moreover, by comparing the water-table levels with river surface levels it was fair to deduce that nearly all the underground water flow went to augment the Nile flow. Would not it be instructive, therefore, to plot a

new diagram showing what the contour lines would look like after the enlarged Aswan Reservoir had reached its top level? It could be predicted that at least near the reservoir the lines would be affected and the hydraulic gradient of the underground water would be flattened upstream of the dam but steepened downstream. More water would therefore enter the river downstream of the dam. In other words, the water coming from the reservoir into the rock upstream of the dam would ultimately find its way into the river away to the north at a lower level. There would, of course, be an intermediate period, lasting for a number of years, when large volumes of underground rock were being charged with water, but, after that, seepage water would merely by-pass the dam without permanent loss.

313. That led to a comforting hypothesis. How would it be possible to collect experimental evidence? Such experiments were forecast in §§ 227 and 231. Since the Author had mentioned borings in the river-bed, it might be asked whether or not any trial borings had been made in the rock away from the river, and, if so, did the water levels respond to the annual rise and fall of the reservoir's surface a few kilometres away? If such sympathetic movements were detected, they might give a measure of the permeability of the rock. Laboratory experiments with a simplified model with fine sand might enable the flow lines to be discerned, or at least inferred. Meanwhile, thought might be given to another kind of movement that the rising water in the Aswan Reservoir would engender. Human beings would be affected and they might have to move a long way. It was understood that plans were under way to accommodate the Sudanese displaced by the large reservoir on a new area hundreds of miles away; was this project to be carried out?

Mr N. J. Cochrane (Senior Engineer, Sir William Halcrow and Partners) said that the substantial drop of 22½% in the average annual discharge of the Nile at Aswan at the end of the 19th century was of great technical interest to hydrologists. It could be attributed to an overall reduction of rainfall of a mere 2% or so because that was what happened in low-yield tropical catchments where run-off was proportionately more variable than rainfall. On the other hand such a persistent reduction in rainfall would also have caused a significant change in the ecology of the catchment, and that was not likely to have passed unnoticed.

315. The change could also have followed a change to a more accurate method of gauging, but in that case Mr Cochrane would have expected the earlier data to have been adjusted.

316. The Author had now suggested that the change in average river flow was due to changes in seepage phenomena, and his supporting evidence was very substantial.

317. If the Author's deductions proved correct there was certainly not going to be much left of the great sources of power in the Nile for the use and convenience of Egyptian man for many years after the construction of the High Dam.

318. The Author's alternative proposals were so meticulously presented that he could not make much useful comment on them. He nevertheless congratulated the Author on having diverted the Nile from the statistical netherworld through which it had apparently flowed for so long. If draught was plotted against storage the consequences of this change of course appeared to be entirely beneficial.

319. Mr Cochrane believed, however, that the Author might have developed his hydrology to further logical conclusions with advantage. He hoped to convince him by recalling that in his contribution to the discussion on the Nile Paper by the late Mr Morrice and Mr Allan⁴⁰, Mr A. N. M. Robertson had drawn attention to the remarkable persistence of Colonel Rawson's cycle in the flow of the Nile and its tributaries. His results might be summarized by saying that there had been three "Southern" and three "Northern" cycles between 1899 and 1955. The average Nile discharges in those had been, alternately, 81, 88, 81, 85, 78, and 87 mld. Hence, in that period of 56 years there had been no anomalies in the succeeding rises and falls in the averages.

320. Mr Cochrane's own researches had been concerned with cycles of shorter

period which, using the data given for Aswan in Appendix I, he illustrated in Fig. 16. The Author's data were not the same as the earlier data adduced by Dr Hurst because the Author had, more logically, used hydrological, and not calendar, years.

321. All the data were plotted as 3-year means on the diagrams which would be seen to show cyclical elements in their behaviour. The data had been compared with the turbulence or rate of change of sunspots and there appeared to be a fairly well marked qualitative correlation.

322. On the assumption that variations in our climate should basically follow variations in incident solar energy, Mr Cochrane had decided to use the only long-term data available on solar variations—sunspots. However, he did not know whether a

FIG. 16.—CYCLICAL VARIATIONS IN THE FLOW OF THE NILE

sun with, say, a hundred spots produced more heat than one with no spots at all. Indeed, the variations in the Smithsonian solar constant were very limited.

323. It seemed desirable, therefore, to clear the mind of any conception of magnitude of energy in association with sunspot numbers as such. (As an analogy, one could not judge the momentary intensity of fever in a child suffering from chicken-pox by the number of spots on its skin.) The turbulence of sunspots was judged to be a possible indicator of changes in the output of energy and this was illustrated in Fig. 16 in a primitive form as rate-of-change of annual sunspot numbers.

324. It was not easy to deal with such correlations by any of the conventional statistical techniques because:

- (a) the data were not events; they were all averages, and different statistical conclusions about the significance of the correlation would arise from varying the time increment used in averaging;

- (b) there might be no consistent average value and a variable average might have to be considered; and
- (c) the sequence of the data was important and they should not be lumped together.

325. The essence of the matter was that, using the flows in hydrological years, the Nile behaved in a clearly cyclic manner at Aswan and it did not matter in the least whether this could be fully explained at present. All that mattered was that the river persisted in behaving in such a manner, and if that was ignored then the control of the river must inevitably be less effective than it might be.

326. The timing of the Rawson cycle was accurately predictable and that of Mr Cochrane's cycle less so. The magnitude of Rawson's variations were fairly regular and not great. The magnitude of Mr Cochrane's variations were greater and less definite. Using both systems he believed that reasonably accurate predictions of the trend of behaviour of the Nile, and useful predictions of the quantity of water to be expected, could be made. He mentioned that he had already used a similar method on Lake Nyasa for 3 successive years⁴¹, with considerable success as regards trend and some success as regards magnitude.

327. While this should amplify the knowledge of those who would control the waters of the Nile, a change in the outlook of those who used the water would be an essential corollary. If they were conditioned to believe that there was some magical long-term average draught then they might be disappointed. If their cropping plans could be more closely linked to the long-term trends in the river's behaviour a more efficient and less expensive system of river control could be envisaged. Mr Cochrane suggested that there should be periodic Irrigation Water Reviews in Egypt, just as there were Farm Price Reviews in Britain, so that the farmers would have a basic measure of security on the one hand and a certain amount of freedom to make the best they could of it, on the other.

Mr J. Guthrie Brown (Partner, Sir Alexander Gibb and Partners) confined his remarks to the High Dam. The Author seemed to consider that to some extent the construction of the dam might be a hazardous undertaking. It might be of interest to give an indication of the background to the design of that dam. The design had been developed by a Board of Consultants appointed by the Sadd-el-Aali Authority and consisting of six of the most eminent engineers in the world who had specialized in large dam design and construction. The Board of Consultants were: Professor Karl Terzaghi, Mr I. C. Steele, Professor Lorenz G. Straub (U.S.A.), the late M. André Coyne (France), Dr Max Pruess (W. Germany), and during the initial studies, the late Sir Murdoch MacDonald.

329. The Board of Consultants were entirely satisfied that the design which they had developed was adequate and that the dam could safely be constructed. Only a bold man would argue against such a decision.

330. Mr Guthrie Brown's firm had been appointed by the Sadd-el-Aali Authority to collaborate with those consultants in preparing the detailed designs and the contract drawings and documents necessary to enable international tenders to be invited for the work. All studies of evaporation, seepage, or siltation in the reservoir to be formed by the dam were undertaken by the Authority's own engineers and hydrological advisers.

331. For political reasons the original offer by the United States and British Governments to provide certain funds towards financing the scheme had been withdrawn. Subsequently, an offer by the Russian Government to finance and undertake the preliminary stages of the work had been accepted by the United Arab Republic Government. At that stage it was interesting to note that although the Russians were to undertake the preliminary construction work, Mr Guthrie Brown's firm was still retained for the design of the main dam itself. Later, however, further financial assistance had been offered by the Russian Government provided they were responsible for the design of the whole of the works. Agreement had been reached between the two

Governments on that basis; as a result the Board of Consultants was dissolved, and in March 1960 his firm had ceased to be connected with the scheme.

332. The cross-section of the dam shown in Fig. 5* was an early proposal and had later been modified by the Board of Consultants and by his firm in many respects. Since then he understood that there had been further substantial modifications by the Russian engineers in the design of the dam and the diversion works.

Mr Alexander McDonald (Secretary, Institution of Civil Engineers) observed that the advice of Sir Murdoch MacDonald had been sought by the Egyptian Government during all the design work and he had considerably amended the designs. Sir Murdoch had handed to the Secretary copies of the correspondence.

Mr F. A. Sharman (a Senior Engineer, Sir William Halcrow and Partners) confined his remarks to two aspects of the Paper, namely, the anticipated range of annual river flow, and the rate-of-seepage problem. He said that the Author, after pointing out certain defects in the calculations by which Dr Hurst, and later Fathy and Shukry¹², had established the overyear storage required for a given drought, had proceeded to brush aside any speculation on how future flows might differ from those in the records. He had proposed that the effective storage should simply be made equal to the maximum deficit recorded in the 55 years of records, neglecting the worst year on the ground that it ought not to happen more often than once in 240 years.

335. That was a disarmingly simple approach, and sounded like bluff commonsense. However, the stakes were high and Mr Sharman believed that it would be wiser to try to make a considered forecast of the effect of future variations. Fathy and Shukry had pointed out the imperfections in Dr Hurst's analysis, and indeed Mr Sharman had remarked on an aspect of that matter more than 4 years ago⁴². Fathy and Shukry's own treatment did not seem to be correct in the matter of losses, as the Author had said. Nor was there anything sacred about their basic assumption, that the recorded values were the most likely ones to recur, but that they might occur in the most unfavourable order. At the same time this did seem quite a reasonable line of approach, and a more prudent one than anything based on an expectation that the past would repeat itself, without allowance for the probabilities of better or worse combinations, or attempts to foresee the effects of cycles or persistences that might be characteristic.

336. In fact, the Author had not really given his reasons for rejecting Fathy and Shukry's method, except in the matter of losses. Would it not have been more logical either to correct the calculation, or to demonstrate how it conflicted with a reasonable estimate of future variation?

337. On the second question, that of seepage, Mr Sharman had no detailed knowledge of ground-water conditions in the Nile area, but in the course of investigating the hydrology and anticipated minimum flows in some small river basins in British Guiana, it had been found possible, by daily readings on a network of observation wells, to determine the variation in direction of ground-water flow, and the order of magnitude of positive and negative contributions from this source to the river flows. It seemed surprising that more definite data had not been accumulated over the years to support or disprove the very important suggestions the Author had made as to the exchange of river and ground-water in the Nile basin; had observations designed to settle the question now been initiated?

338. Dr Hurst, in his contribution, had poured scorn on the suggestion that relatively massive water movement in the rocks in question could take place. It was quite true that with the very flat ground-water table gradients implied by Fig. 13, the net average movement could be extremely slow, but anyone who had pierced a layer of water-bearing sandstone when driving a tunnel would have a considerable respect for the possible immediate yield of this type of rock under medium head, even when the

* A more recent cross-section is shown in Fig. 22, p. 412.

permeability measured on samples was low. It was necessary to distinguish between the slow creep of water through an aquifer in conditions of virtual equilibrium, and the much more rapid transmission of applied piezometric pressure changes through interstitial water, which could initiate movement in the vertical as well as the horizontal direction over such large areas as to make the quantities absorbed or yielded in a year very significant. A year's daily records from a few dozen observation wells, along with pumped well tests at strategic points, would be worth a mountain of speculation on that point. Once a plausible picture of the ground-water movements accompanying river-level fluctuations under existing conditions had been established, not only was it possible to visualize much more reliably the effect of creating a new reservoir, but also the credibility of losses determined by past river gaugings could be tested, and many of the uncertainties on which there had been unresolved argument could be greatly reduced. Schoeller⁴³ had given useful information on the whole problem, and had pointed the way to further research.

339. It could not be denied that the risk of excessive seepage in an area where vast volumes of rock and soil were to be wetted up for the first time in their history was sufficiently great to justify a very full and energetic investigation, and it would be interesting to know whether the terms of reference of those who had designed and re-designed the High Dam included the task of assessing the probable reservoir seepage losses. In particular, could the Author say whether Professor Terzaghi had been asked to consider this question, and if so, whether he had thought it possible to give a reliable answer from the existing data?

Mr J. K. Hunter (Consultant, Sir Alexander Gibb and Partners) felt it appropriate to say a word on behalf of the engineers of a bygone generation. The Author had expressed the opinion that the construction of the Gebel Aulia Dam had been a mistake. That seemed rather a harsh judgement. The material benefits which had been received from that dam since its construction had no doubt greatly exceeded the original cost of £3,500,000. It might well be that today such a reservoir would not be constructed on that site, but since the site had been chosen half a century ago, in 1910, many changes had come about; it should not be forgotten that an *ad hoc* decision had had to be taken in the light of the circumstances at the time and also, Mr Hunter suggested, with the knowledge that the decisions taken might one day turn out to be less wise than they had seemed then. That was inevitable. Even if the dam were to be abandoned in 10 years' time (which was probably the earliest date by which an effective replacement could be provided) it would have served for nearly 50 years, and the Egyptian Government would have recovered the original expenditure many times over.

341. The development of a great river basin such as the Nile involved enormous effort and the expenditure of vast sums of money. Capital and human resources were always limited. What was important was to spend wisely those resources which were available at any given time. That, indeed, was the underlying theme of the Author. No scheme of development could ever be regarded as final, first because knowledge was always increasing, and secondly because it was not possible to escape the inevitability of changing circumstances. Although a particular decision might be right at the time it was made, there could be no assurance that in 40 or 50 years' time it would still be regarded as satisfactory.

The following contributions were received in writing.

Mr D. M. R. Esson (Editorial Assistant, "Design and Components in Engineering") referred to the statement in §§ 134-137 that the transpiration from a papyrus-covered surface was about three times that of an open water-surface, and that the sponge effect of the Sudd would no longer be required with the century-storage system of Lake Victoria. The Author wished to stop that excessive transpiration by draining, thereby offering an enormous area for cultivation. It would, however, be a tragedy if that

process were to dry the air of that neighbourhood and thereby encourage the southward advance of the Sahara Desert. Furthermore, would not Egyptian agriculture suffer by being deprived of the accretion of organic detritus from that area?

343. Fig. 4 showed how the average discharge of the Nile had fallen from 107 mld cu. m for the period 1871–1901 to 92 mld cu. m for the period 1902–53. It must be a cause of great anxiety to those responsible for the welfare of future generations of Egyptians, not to know whether this variation was cyclic or permanent. If it was permanent it might be due to Man's interference with Nature in the Southern Sudan and beyond: no doubt it would get worse, and the provision of additional storage of the Nile waters would acquire a fresh urgency.

344. The passage of the Nile through the Libyan sandstone beds between the Second and First Cataracts, mentioned in §§ 226–235, was most interesting. With the inauguration of the Sadd-el-Aali, could not a further increase be expected in the output of the wells in the Western Desert? Those remnants of once-thriving communities of Roman times might well be on the verge of a new era, and a carefully drawn-up plan for their resuscitation should not be low down in the list of priorities of work awaiting the technicians of Egypt. It was reasonable to suppose that the increase of vegetation consequent upon the increase of water might set up a chain reaction to produce, over the next 200–300 years, a great crescent of flourishing oases from Kharga to Bahariya. If that reasoning was correct, seepage losses in the Sadd-el-Aali would be but a prudent investment, of a long-term nature it was true, but productive of a worth-while dividend.

345. In §§ 108–128 the Author had mentioned an ingenious method of providing nearly 12 mld cu. m of reserve water in the Wadi Rayan. From a cursory examination of Fig. 6 it would appear that a barrage at Biba might well be duplicating the works at the head of the Yousfi Canal, so that much money might be saved by widening and deepening that artery, at least so far as was necessary to give access to the Wadi Rayan. Developing yet further the concept of increased cultivable area versus direct water storage, would it not be more advisable to develop the Wadi Rayan in a similar fashion to the Faiyum depression? That would provide about 160,000 feddans of cultivable land at no great distance from the Nile, nor indeed from the populous city of Cairo.

346. It would be interesting to have a plan annexed to the Paper showing the areas to be inundated in the Sadd-el-Aali.

347. Finally, it would be a fascinating exercise to consider the problems of the upstream river ports, faced as they would be with a rise and fall of 35 m.

Mr J. W. Burns (a Senior Civil Engineer, Geo. Wimpey & Co. Ltd) remarked that Nile control, like most excessively complicated subjects, had to be reviewed from time to time, not only on account of experience obtained through the execution and operation of various control works, but in the light of statistical discoveries, mathematical computation, and the needs of the vast tracts of land either perennially irrigated, or which it was desired to bring under irrigation.

349. In his first Paper the Author had rightly considered that any drastic departure from the time-honoured system of flood-water storage must be given very careful thought before adoption. The completion of the Sadd-el-Aali would ensure that a vast quantity of water would be available for reclamation in Central Upper Egypt, and in the Delta, but unfortunately it would be clear water, deprived of the Nile silt. That would be the case because storage in the new reservoir, or, more specifically, the old reservoir heightened, must be commenced whenever the flood waters of the Nile arrived at the dam site, thereafter only a percentage of the flood waters would be allowed northward into the river channel at the Aswan Dam, though sufficient of course for irrigation needs to the north. Immediately, and for ever after, the cultivator would be deprived of the silt-laden flood water, which he had relied upon to fertilize his farm or holding as far back as he could remember.

350. The filling of the dam to the height desired might be a task often impossible to achieve, and if attained no-one could ascertain beforehand what storage losses might

result from seepage at the higher levels, and what percentage of that seepage might again return to the reservoir when the lower levels were attained, due to the withdrawal of storage water from the reservoir. Again, the silting of the reservoir which must result could only produce a very serious position in the future, say in 300 years' time, when the storage capacity of the reservoir would be reduced to a very small percentage of that which existed at present.

351. Mr Burns remembered a Nile flood period about 35 years ago, when the usual timber needle dam was not erected at Mansoura Lock on the Bahr-el-Seguir, in order to keep a flow of water in the channel connecting the Lock with the River Nile. At the end of the flood period it was found that the channel had silted for a depth of 4 m, about 14 ft. That gave some idea of the seriousness of silt deposit.

352. The execution of one or two dams to produce reservoirs with a lesser total storage would be safer and would ensure an economical utilization of the funds to be contributed.

Mr I. C. Forbes (formerly with the British Section, International Commission on Irrigation and Drainage) said that records of the flow of the River Nile at Cairo had been taken since A.D. 641 and had continued to the present day with the exception of a 300-year break from A.D. 1450. It would certainly be possible to gauge any cyclic order of high or low flows throughout those years. That the River Nile had undergone changes in character during the past 3,000 or more years must be admitted. The Biblical story of 7 years' famine, confirmed by the historian, Josephus, could only have been caused by the failure of the yearly Nile floodings. It was said by geologists of repute that a river used to flow from the Delta of the River Nile near Cairo to a point near Suez, and on that river had sailed the expeditions to the "Land of Punt"; that had never been clearly defined and could mean a region between Somaliland and Mashonaland. The Sudd must have existed from time immemorial and might possibly have been a huge lake. There was a parallel to that. Lake Chad was discovered by Barth in 1851, and the discovery confirmed by Vogel some years later. It was stated to be a huge expanse of water in which game of all descriptions abounded. Today it was said to be a tract of stinking swamps. According to the "Harris Papyrus" of Ramases IV, it was recorded that Ramases III sent an expedition of 10,000 men to the "Land of Punt" and discovered "The Lake of Crocodiles". An expedition of that size could only travel by, and live off, the land and therefore could only follow the River Nile to its source. The Sudd might be the "Lake of Crocodiles".

354. The Author had stated that the flow of the Blue Nile at Tana was only 7% of the total Blue Nile flow. There was a legend based on historical fact that a Duke or Ras of Shoa, about A.D. 1250, decided to pay off some score against the Egyptian Moslems and dammed the River at Tana with huge earthworks, resulting in famine and starvation to the Egyptians. The remains of the earthworks were said to exist still. If all that was true there must have been a complete Nile failure co-incidental with the construction of those earthworks. Was that the Author's opinion?

355. Turning to losses by evaporation, the United States Department of Agriculture had given State's figures on reservoir evaporation, which could be generalized as follows:—

Eastern industrial States north of Mason-Dixon . . .	39 in. loss per annum
Eastern agricultural States south of Mason-Dixon . . .	50 " "
States of Oregon and Montana	26 " "
States of Arizona and New Mexico	96 " "

Arizona and New Mexico were comparable in climatic conditions to Egypt at Assuan, and that suggested that any impounding works should be sited on high lands, where evaporation losses would be more favourable. It must not be overlooked that water evaporated into clouds by day, would condense again on the cold lake surface by night, unless the clouds were driven off by winds.

356. On flow recovery, the Colorado State Engineering Bureau had formerly conducted experiments and had found that in a distance of 400 miles, there was a gain of 575 cusecs over that at the upstream measuring station with no tributary flow between. Similar experiments in the same State had confirmed that water was returned by seepage from impounding works, the quantity being dependent on underlying strata, and their direction of slope, and texture.

Mr A. M. R. Montagu (Consultant, Sir Murdoch MacDonald and Partners) referred to the probable effects, in respect of silt, of the construction of the High Dam at Aswan.

358. The disaster at Islam on the Sutlej River in September 1929 was germane to the subject. Very briefly, the Punjab Government constructed three major barrages on the Sutlej River at Ferozepur, Suleimanki, Islam, and a fourth at Panjnad. The working level at each of the barrages approximated to normal flood level and was therefore about 12 ft higher than the normal flow level. It followed that the pond level above each barrage formed an immense "silt trap". The silt in the river was deposited above the barrages and the issuing water was practically silt free.

359. Retrogression of the river-bed at Ferozepur was appreciable. It was serious at Suleimanki but at Islam it was disastrous. During the hot weather of 1929, on a rising river, with all the off-taking canals in flow, "piping" below the floor of the barrage led to its failure. Some of the central bays were completely destroyed and the adjacent bays damaged. Lessons could be learnt from that disaster.

360. The construction of the High Dam at Aswan would have a corresponding result. All water entering the storage would deposit silt. The issuing water would be silt-free. Retrogression of the river-bed below the dam would follow. The extent of that retrogression would be appropriate to the river discharge, the average silt content of the river, and the extent of the storage. It also followed that the storage capacity would deteriorate correspondingly.

361. Retrogression would have certain consequences. All structures below the dam would have to be adequately protected.

362. The Author clearly appreciated the very considerable advantage of using "off-line" storage such as the Wadi Rayan Depression. The silt deposited therein would be the silt content of the stored water only, leaving the river to flow unaffected, during that portion of the year when actual storage was not in progress (§ 128). But Mr Montagu submitted that the concomitant advantage of checking retrogression was of vital importance and should be emphasized.

Mr R. P. Black (Scientific Consultant, Public Works Ministry, Cairo) said that the Author's assertions, contradictions, and misapprehensions might not be so obvious to those who had not immediate access to all the data, and were not familiar with irrigation practice, past and present, in Egypt.

364. The Author had given yet another estimate of the optimum capacity of the reservoir in the High Dam scheme. If it was to demonstrate his quite remarkable insight into Hurst's statistical approach, which had enabled him to reduce the accepted capacity by half, and in so doing to rid himself of that troublesome 1913-14 year, he had certainly succeeded.

365. The Author was against the High Dam project, and § 107 summed up his attitude, as followed: "Finally it may be stated, that both the conception of the High Dam and its rockfill type of construction have originated from fanciful ideas which are foreign to Egypt, and at any rate, constitute a complete reversal of the time-honoured irrigation policy of the Nile".

366. Mr Black dealt only with the ideas underlying the conception of the High Dam project and the Author's alternative project. Its type of construction could safely be left in the hands of the Commission of eminent engineers responsible for the design of the dam.

367. What was that "time-honoured irrigation policy of the Nile" to which the

Author had referred? It could be summed up in his own words, that reservoirs constructed on the river must allow free and unrestricted passage to the whole of the silt-laden flood water.

368. Within the framework of that postulate, over-year storage had been discussed in Egypt for half a century, but the idea had never got beyond the accumulation of a reserve, in the great lakes of Central Africa, to meet contingencies that would arise, if certain specified low years occurred in the future, and the transmission of the water, through or round the swamps of the Southern Sudan, in such manner as to avoid the enormous losses of the existing channels. Indeed, the study had eventually resolved itself into ways and means of avoiding the enormous losses of water in the swamps.

369. In 1938, when the late A. D. D. Butcher produced his Jonglei Canal Diversion Scheme, which in its essentials still remained the policy of the Egyptian Government, he remarked that there were no reliable means available to determine how much storage in Lake Albert was either desirable or necessary, and therefore that the Lake Albert project must wait until the menace of low years rendered it essential.

370. In 1946 "The Nile Basin", vol. 7, was published¹ in which the Authors had attempted to foresee the future development of the Nile up to the limit of the clear water supply. In doing that they had demonstrated that any further advance beyond the then existing state of development must be by over-year storage, which they placed on a scientific basis for the first time.

371. Subsequently, Hurst, developing that theory of over-year storage, had reached the following conclusions:—

- (a) That natural phenomena in general could only be considered Gaussian random events, if their order of occurrence was ignored.
- (b) That the average storage R required to guarantee the mean each year for a period of N years might be expressed by an equation of the form:

$$R/\sigma = (N/2)^K$$

- (c) That the storage S to guarantee a draft D less than the mean M could be expressed by an equation of the form:

$$S/R = -0.08 - 1.05(M - D)/\sigma$$

- (d) That there was no such thing as a long-term mean.
- (e) That the range of K in the 691 cases so far examined was 0.46 to 0.91 with a mean value of 0.72.
- (f) That K had a random distribution and therefore its mean was significant and gave the most probable value for the future.

372. Those were the "fanciful" ideas on which the conception of the High Dam project was based, but what was "fanciful" about them? By foreign the Author probably meant new or *startlingly* new to Egypt; this would be agreed, and perhaps to a very much larger part of the world.

373. In setting out his alternative to the High Dam project the Author had followed the "time-honoured practice" of accumulating a reserve to meet a specific contingency, and had then asserted that that reserve would "guarantee" for the future a certain annual Nile discharge—his predecessors had never been so bold.

374. He had considered only the years of the present century, had rejected the lowest year 1913–14 on "statistical grounds", and had found that the maximum deficit of any year below an annual total of 75 mld cu. m was 12 mld. The problem was then solved and he had declared that an over-year storage of 12 mld cu. m was sufficient to guarantee a future annual discharge of 75 mld cu. m. During a discussion in 1960, Dr Hurst and Mr Black⁴⁴ had drawn attention to the fact that the Aswan series of years of the present century was a very remarkable one, and that the probability of its recurrence in the future was a very low one, much lower than that of the recurrence of a year like 1913–14 which the Author had rejected. Having fixed the required over-year storage at 12 mld the Author had found it could be accommodated in the Wadi Rayan,

and had claimed that a Wadi Rayan project to hold a reserve of 12 mld cu. m was economic because of the seasonal power now available at Aswan, which could be used to pump the water out as required.

375. An inspection of the yearly totals at Aswan in the 20th century had shown that the pumps would have remained idle during the whole period 1931-38.

376. The remainder of his project was to erect annual storage reservoirs, to distribute his 75 mld guaranteed usable annual total discharge as required. He had balanced his summer water account as followed:—

Total summer water required	39 mld cu. m
Natural flow of the river	15.4 "
Aswan Reservoir	5.0 "
Sennar Reservoir	1.0 "
Roseires Reservoir	3.5 "
Merowe Reservoir	10.0 "
Second Cataract Reservoir	4.0 "
	<hr/> 38.9

The 15.4 mld given above for the natural flow of the river (Feb.-July) was actually the mean for the whole period from 1871 onwards, for the years of the present century it was only 13.0, and there was a 75-mld year among them, when it was only 9.5 mld (1921-22). Hence, if the "guarantee" meant anything, the annual storage must cover this year and therefore must be increased by nearly 6 mld cu. m.

377. Roseires Reservoir could take another 3 mld, which left 3 mld more to be stored on the Main Nile. Thus, total annual storage was 29.5 mld cu. m, of which no less than 22 mld was in the Main Nile. Put more simply, in a 75-mld year like 1921-22:—

	mld cu. m		mld cu. m
Flood water	= 65.5	Summer water	= 9.5
Requirements	= 36	Storage	= 29.5
			<hr/>
Storage	= 29.5	Total	= 39

It was impossible to forecast the flood, so that even in an average year, or indeed in any year, the bulk of the storage must be filled on the rising flood. It would be possible to keep a capacity of 8 mld cu. m available, in case flood protection might be necessary, to be filled as soon as all danger was past. That flood protection of 8 mld cu. m, to which the Author had referred, assumed that the river branches were capable of carrying 670 million cu. m/day when required.

378. It was quite impossible to accept as a reasonable proposition that the river branches, which for many years might carry nothing at all, and on the average a very small discharge, would be capable of carrying 670 million cu. m per day at short notice whenever required.

379. In accordance with the "time-honoured practice", it was customary to retain 20% of all storage to meet contingencies, from the highly variable river supply in July. Even during the 20th century, and omitting that troublesome 1913-14 year, it had varied from 2.5 to 8.7 mld cu. m, with an average of 4.1 mld⁴⁵.

380. The July reserve, amounting in that project to about 6 mld cu. m, would just be sufficient to ensure that restrictions would not need to be enforced, in July, more often than 1 year in 10. It involved, however, a waste to the sea of about 2 mld cu. m on the average.

381. The only way that waste could be avoided would be to hold the reserve in Wadi Rayan, but that was ruled out because:—

(a) there was no seasonal power available at that time of year;

- (b) even if there was, the pumping installation could not deliver 6 mld in a month; and
- (c) even if the pumps could deliver the water the proposed channel could not carry it.

382. Losses involved in the Author's alternative project were:—

	mld cu. m
(a) Loss on annual storage reservoirs/year (there was no site on the river where the loss was less than 10% of gross storage except Aswan)	3
(b) Loss on Wadi Rayan Reservoir/year	1
(c) Loss due to necessity for July reserve/year	2
(d) Water sent to the sea/average year	8
Total	14

The Author's claim that the water unavoidably sent to the sea, on the average, might be used for the development of basin irrigation was inadmissible, because in quite a number of years there was none at all.

383. Referring to the problems of silting and erosion, Mr Black said that the Author's annual-storage reservoirs would begin to silt up from the very beginning, and in doing so would, just as effectively as Sadd-el-Aali, de-silt the river, and over a longer reach. There was no foundation for the assertion, in § 22, that "Such reservoirs have now come to be regarded in Egypt as an economic proposition".

384. Further, the Author's project would involve a discharge downstream Aswan of 870 millions/day, of clear water, as compared with about half of that in the High Dam scheme, during a very high flood.

385. A study of "The Nile Basin", vol. 5, and a visit to the region concerned would convince him that his project for the draining of the Sudd region was impracticable.

386. Finally, the gains and losses between Halfa and Aswan, on which he had based a remarkable theory of the dire effects of the High Dam scheme, existed only in his imagination.

Mr Duncan Kennedy (formerly with Sir William Halcrow & Partners) said that reference was made in § 12 to the considerable quantity of silt carried by the flood waters of the Blue Nile and the River Atbara. When elsewhere in the Paper silt was referred to, the Author no doubt had in mind similar material, washed out from the soil in areas of heavy rainfall and carried in suspension in the water. There was, however, another source of accretion to the river-bed—wind-blown sand from the desert.

388. Long stretches of the Nile passed through desert country with practically no rainfall, and anyone who had experienced a desert sandstorm would appreciate what a large quantity of sand could be moved by the wind in a single day, notably in the period of the Khamsin winds. The sand varied in size down to fine dust, but it could be assumed that little of it would be carried in suspension in the water, and the bulk would be transported as bed load. For that reason its effect on irrigated land would be small, but on the other hand it might, because of its weight, have an appreciable effect on the river-bed by slowing the downstream movement of the bed material, and it would, of course, act as a make-up material to replace normal bed losses through current erosion. What were the Author's views on that factor, and on the possible effect on the river-bed below Aswan of the arrest of such material by the High Dam? Would he also say whether any attempt had been made to estimate the quantity of desert sand thus trapped each year by the river?

Mr C. T. Gardner (Retired, Kenya), in drawing attention to Fig. 13, which showed contours of the Libyan water-table, said there was no indication of the contours on the

eastern side of the Nile south of Wadi Halfa; it was probable that the contours on the east would somewhat resemble those to the west.

390. When the Port Sudan-Atbara railway line was being built, wells had been sunk at several railway stations between Thamiam and Atbara (Thamiam lay somewhat to the west of the Nile/Red Sea divide). The ground level thereabouts was 2,500 ft; water was found at depths which ranged from 60 to 130 ft; at the well at Ogrein water trickled in through the decayed and fissured granite. At times, sheets of water in many places, perhaps 500 yd wide, had flooded on to the railway from the higher levels to the south, and had swept away many miles of it: as an indication of the volume of flow, Mr Gardner mentioned that in 1908 about 1,500 sturdy men worked continuously for almost 3 months before the railway could be reopened. He did not think that any of that water flowed on the surface into the Nile: it went underground.

Mr G. W. Murray (formerly Director, Desert Surveys, Egypt) remarked that the Author had chosen to ignore Professor Hellstrom's careful experiments on the permeability of Nubian sandstone and preferred to rely on an instance given by the late Mr H. T. Ferrar of the Egyptian Geological Survey of a percolation rate through coarse sand in the Egyptian Delta of 150 m/day (§ 230). That related to a rise in the trunk canal, called the Bahr Shibin, which was reflected in a tube well in an adjacent field, well below the surface-water level of the Bahr Shibin, within 24 hours. In 1909, Mr Ferrar had shown Mr Murray that well and had explained that the rapid interconnexion was due to the fact that, though the banks of the Bahr Shibin were of Nile mud, its bed was composed of coarse sand and was leaking badly. That quite isolated instance gave a rate of flow just 3,650 times that obtained by Hellstrom for percolation through compact sandstone. But even that did not satisfy the Author, who had suggested "it is likely to be exceeded, however, in the Nubian sandstone".

392. In § 233 it was stated that "increase of rainfall (at the fountain head) would produce appreciable flow of ground-water causing a rise in the water-table (at Aswan) though, of course, with some time lag". Since the fountain head concerned lay 850 miles away in Central Africa the time lag, even at his grossly exaggerated rate of percolation, would amount to 25 years—a period surely long enough to iron out rainfall variations. (The much more probable rate found by Hellstrom would give 91,200 years!)

393. In § 233 the Author had attributed the great increase in the output from the Dakhla wells during this century to "counter pressure in the Aswan Reservoir". The fact was that that increase was due simply to the many more wells that had been sunk and that the supply as opposed to the output was falling off. That was proved by the drop of 5 m or more in the local water-table both in Kharga and Dakhla.

394. Another indication that there was no significant loss from the Nile was that artesian water contours, shown in Fig. 13, did not bulge out away from the river as they should do from an intake area. In fact, if the extension of the Libyan aquifer below the river to the eastern desert were accepted, the Nile would run in what Hellstrom termed "a hydrologic valley".

395. It seemed very unlikely that any of the water from the Libyan aquifer eventually found its way, as the Author had suggested, to the sea. For by the time it reached the chain of depressions extending from Jaghub to Maghra, where much of it evaporated in the Qattara depression, it was already well below sea-level. Farther north the strata appeared to be impervious. For, in the line of diamond drill holes which were sunk along the line of Ball's projected tunnel from the sea to Qattara, salt water was found at approximately sea-level in the bores up to 20 km from the Mediterranean. Southward of that, all the bores were dry.

Mr W. N. Allan (Irrigation Consultant to the Government of the Sudan) said that there were many points in both Papers on which the Author's arguments appeared to be invalid and even unrealistic. Mr Allan's remarks were, however, confined chiefly to the

very important questions of the storage capacity required on the Nile, and the location of that storage.

397. Two points should be clearly realized and always kept in mind. First, the extent to which it would be possible to extend irrigation in the Nile Valley, including particularly irrigation in the Sudan and Egypt, would depend on the quantity of water which could be reliably assured in all years, and not on the extent of suitable lands, which in total were more than sufficient. It would therefore be necessary to regulate the whole of the available flows, while at the same time keeping the resulting losses as low as possible. In practice, that would mean that ultimately all flows, whether silt-laden or not, must be controlled and used, so that no water would pass to the sea, except in case of emergency. Secondly, the Author was quite right in pointing out, in § 39, that no amount of regulation on the Equatorial Lakes could do more than a small part of what would be required. The flood flows of the Blue Nile and the Atbara could only be adequately regulated by storage located on the Blue Nile or the Atbara or on the Main Nile, north of Khartoum. The prime question was, how much capacity would be required?

398. In § 67 it was stated that for over-year storage 9 mld cu. m would suffice. The Author had first discarded the year 1913–14 as not requiring provision, on the ground that it had occurred only once in 90 years. But it had occurred, and similar years would certainly occur again. When they did, after cultivation had extended to the stage where it needed 70 mld annually (to use the Author's figure), what was to happen to the people whose whole livelihood depended on it? In such a year there would be only 42 mld, plus 9 from storage, less say 2 for losses, or in all about 49 mld to meet needs of 70 mld. In that part of his argument the Author had ignored the losses. He had also ignored the fact that it was not merely the lowest single year which had to be provided for; it was the maximum cumulative draught on over-year storage over a period when years below average preponderated. In this respect, 1925–27 and 1940–45 had been almost as critical as 1912–15. In the light of those facts, the Author's case for such a small amount of over-year storage as 9 mld was quite unrealistic.

399. The investigations of many variable natural phenomena by Dr Hurst and his colleagues were of great value, and should certainly be taken into account in dealing with particular cases. But where data of river flows were available over a considerable period of years, Mr Allan believed that, on present knowledge, the safest method of estimating the over-year and annual storage capacity required was to ascertain what would have happened during the period under regulation, assuming various amounts of capacity in feasible reservoirs, controlled in feasible ways which involved no fore-knowledge of future events at any time, allowing for the inevitable losses as they would have occurred. When, by repeated trial and error in that way, a satisfactory solution had been found, a reasonable margin of safety could be added, in case of the occurrence of less favourable conditions.

400. Such investigations involved extensive computation. To overcome this difficulty, Mr Allan knew at present of no better method than that adopted by the late Mr H. A. W. Morrice and himself—the use of a digital computer. They had calculated, month by month over the period 1905–52, the discharges of the Nile at all necessary points, and the contents of all the reservoirs assumed to exist, on the courses of the White Nile from Lake Victoria inclusive, the Blue Nile from Lake Tana inclusive, the Atbara, and the Main Nile down to and including the High Aswan Reservoir. As closely as was possible within the capacity of the computer, the calculations allowed for transmission losses, storage losses in all reservoirs, and withdrawals of water for irrigation. The method had been described in their 1959 Paper³⁹. In the present discussion, Mr Allan merely wished to point out some conclusions from the results obtained. With storage up to 100 mld cu. m in Lake Albert, used to the best possible advantage according to the varying contributions of flow from the Sobat, the Blue Nile, and the Atbara, the range of effective capacity needed in addition was found to be equivalent to about 117 mld cu. m in all, reckoned as at Aswan. Of that, about one-

quarter could be regarded, somewhat arbitrarily, as required for annual storage, and three-quarters for over-year storage. Of the total, the equivalent of at least 20 mld cu. m, and perhaps up to as much as 35 mld, could be provided on the Sobat, Blue Nile, and Atbara, including reservoirs already existing (except Jebel Aulia) or in prospect; such an amount would be partly for over-year storage and partly for annual storage. There would remain to be provided on the Main Nile from 82 to 97 mld cu. m, which might be all in High Aswan, or partly also at other sites such as Semna; the latter arrangement would provide more power at the cost of rather larger losses by evaporation. Since the calculations were made for monthly periods, they covered the regulation of the highest floods which had occurred during the 20th century. It had been assumed that flows passing down from Aswan were only those needed for irrigation in Egypt and that no water would pass to the sea even in high floods. It should be noted that the discharges dealt with were not merely the recorded natural flows, but those plus the additional flows provided by the reduction of losses in the Sudd region resulting chiefly from the provision of the Jonglei By-pass Canal, which were found to average 9 mld cu. m/year as at Aswan; the effect was to increase slightly the total range of storage required.

401. Without doubt the scheme of reservoirs assumed in those studies, and the methods of regulating them, could be improved. In that and in other ways, the total capacity required could certainly be somewhat reduced. But it appeared certain that for the full ultimate development of irrigation, reservoir capacity of the order of magnitude indicated by these studies would have to be provided. That conclusion was in strong contrast with that reached by the Author, and was not far short of that reached by Hurst and Black.¹¹

402. The Author was right in foreseeing that when the High Aswan Reservoir was in full operation, practically all the silt load would be deposited in it, and that the clear flows from it would cause erosion and degradation along the course of the Nile in Egypt. The lack of fresh silt on irrigated lands might well result in reduction of fertility. But the maximum extension of irrigation could only be achieved by full over-year and annual regulation of all flows, whether the necessary storage was on the main stream, or in part off-stream, e.g. in the Wadi Rayan. Either the consequences of complete regulation must be accepted, and its harmful results mitigated by remedial measures so far as possible, or silty water must be wasted to the sea, and irrigation limited to little more than its present extent. There were no other alternatives.

403. Mr Allan was unable to accept the Author's arguments for the alleged very large contributions to flows, from underground aquifers in the river-bed, before the building of the first Aswan Dam. Nor could he concur in the Author's forecasts of seepage losses from the High Aswan Reservoir, when filled. The dead storage of 30 mld cu. m would extend to the Second Cataract above Wadi Halfa, a distance of more than 350 km from Aswan; in that length of almost entirely still water, silt would be deposited and no fast flows would occur to erode it. As the reservoir rose and fell within the range of contents above that, the deposition of silt would continue, mostly, it was true, near the upper end of the reservoir at any particular content. That continuing process would tend to diminish the rates of seepage loss as time went on. Evaporation losses would certainly be serious, and it was of prime importance that the policy of regulation adopted should be such as would prevent the reservoir contents from being at any time higher than was really necessary; the investigation of the best arrangements for that purpose was a large and important field of study.

Mr K. E. Snelson (Deputy Projects Manager, Binnie Deacon and Gourley, Baghdad), Consulting Engineers, formerly of the Sudan Irrigation Department when he was seconded to the Jonglei Investigation Team and Southern Development Investigation Team) confined his remarks mainly to the Author's proposals for conserving the waters of the Bahr el Ghazal Basin; the strategy, for conservation of the Atbara, Blue Nile, Sobat, and Equatorial Nile Basins, and the regulation of their water within their basins and in the Main Nile had already been presented in a concise and quantitative way by Morrice and Allan. The conservation of the 14 mld cu. m presently all but lost

annually in the Ghazal swamps (§ 161), would be the last and almost certainly the most expensive stage of Nile development and would present an engineering challenge of magnitude to the engineers of the future who would undertake it. The Author had been bold in suggesting a solution to the problem; Mr Snelson did not think, however, that the Author's proposal was a satisfactory solution.

405. The Author had postulated that it would be possible to draw a steady discharge of 1 mld cu. m/month from the Ghazal through his pumps at Lake No (§ 146) so that the average annual inflow into the Ghazal swamps of 14 mld, only 2 mld, or 14%, would be lost. Long-term discharge records for most of the rivers discharging into the Ghazal swamps were not available, but from gauge records at Wau from 1904 to 1945, it had been estimated⁴⁶ that the annual discharge of the River Jur varied between 1.4 mld (1913) and 8.7 mld (1924). Inflow into the Ghazal swamps would vary *pro rata* between 4 and 24 mld. The Author had stated that "no control by storage or otherwise is foreseeable in these swamps" (§ 170), yet he had apparently expected them to act as an over-year reservoir with only 14% loss!

406. Not only did the annual inflows into the Ghazal swamps vary, but the seasonal variation was even more marked. The Author probably had more data from the gauges installed since 1943, but in 1954 Mr Snelson had calculated that the average monthly inflow varied between 0.1 mld cu. m/month in March and 3 mld cu. m/month in September⁴⁷. The Author also apparently expected the swamps to be also an annual reservoir, and still with only a 14% loss!

407. Mr Snelson then put forward an alternative suggestion for conserving the water of the Ghazal Basin. The fundamental way was to build reservoirs in the rivers *above* the swamps, and to lead to the White Nile the share of their water which was destined for the north by a gravity channel with an acceptable slope which avoided the swamps.

408. The upper reaches of the Ghazal tributaries were virtually unsurveyed so it could not be said with certainty that there were favourable dam sites. Nevertheless, the available evidence was encouraging. The River Sue, the principal tributary of the Jur, was the best-known, since the Wau-Yabio motor road followed its left bank. At Mbiri (Fig. 17) a site had been located and a reconnaissance survey had indicated that a modest dam 30 m high and 2.0 km crest length would form a reservoir of 2.5 mld cu. m capacity. The country between the Nile-Congo Divide and the plains was quite uniform and there seemed little doubt that dam sites could be found on the other rivers. The accounts of attempted navigation spoke frequently of rock bars obstructing progress. Annual rainfall and evaporation roughly balanced in that region so reservoir evaporation losses should be low. Sedimentation of the reservoirs might be a problem, but until records were obtained, the frequency of the need for replacement storage could not be assessed. The catchment areas were mainly wooded.

409. The water conserved in the reservoirs might be used most economically to irrigate land on the fringes of the former swamps or those former swamps themselves. If some water was allocated to the north, a collector channel would be constructed to deliver it into the Bahr el Jebel upstream of the barrage proposed for the Jonglei Scheme. Thence, it would be passed through the Atem head regulator and into an enlarged Jonglei Canal. The maximum contemplated water level upstream of the Jebel barrage was 418.95 m⁴⁸. Accepting the Author's slope of 5 cm/km as the minimum, the level at the River Jur, 400 km from the outfall at the Atem Head, must be 20 m higher plus, say, 6 m for head losses across structures at the river intakes, i.e. elevation 445 m or 19 m above normal high-water level at Wau which would fix the intake approximately 50 km upstream. The country through which the canal would pass was a laterite peneplain which should be no obstacle to modern earth-moving machinery. Beyond the Jur, the canal would be extended to the River Lol making it 600 km long. The approximate alignment of the canal was shown in Fig. 17. More detailed survey of the country might indicate the possibility of a line giving a greater slope.

410. The scheme proposed above was of some magnitude, but no more so than the California Water Plan or the Indus Valley Project which were about to be undertaken.

411. In conclusion, Mr Snelson referred to the Author's suggestion in § 173 that the dam proposed at Bedden for a balancing reservoir might be raised to give a minimum power head of 160 m. Had a survey been made for such a high dam? On the basis of the 1949 survey, a dam 20 m high would be 1·2 km long; from Mr Snelson's recollection of the valley at Bedden, he estimated that the Author's high dam would be at least 10 km, and probably 20 km in length! Did the Author really consider that a better proposition for power than a series of small dams, developing roughly the same head between Nimule and Rejaf? The necessary storage in Lake Albert could be obtained by quite a modest dam at Mutir.

FIG. 17.—MBIRI DAM SITE AND PROPOSED BAHR EL GHAZAL COLLECTOR CHANNEL

Mr H. F. Wilmot (Civil Engineer, Sir Alexander Gibb & Partners) drew attention to the serious lack of agreement among the experts on one of the fundamental aspects of river control—the determination of the amount of reservoir storage capacity to achieve a defined objective. In the Nile this objective was to secure for the benefit of Egypt a controlled annual discharge of 72 mld cu. m in every year.

413. The Author had given two different values for the size of the necessary reservoir, as derived by Hurst and by Fathy and Shukry respectively. In addition he had given three possible values of his own, the smallest of which left out of account the abnormal year 1913-14 (§§ 68-69).

414. All five values, which had been based on the same set of river-flow records, made allowances for the effects of evaporation and loss of storage as the result of siltation. They led to estimated *gross* storage volumes ranging from 65.2 mld to 130 mld—a ratio of 1 to 2. If the allowance made for evaporation and siltation were subtracted from the gross figures the differences between them would become even more startling as Table 17 showed. Details of how these figures were obtained were shown in Table 18.

TABLE 17

Authority	Net storage values: mld
Hurst	65
Fathy and Shukry	41.8
Ahmed—first method	20
Ahmed—second method	30
Ahmed—omitting year 1913-14	9

415. To make the comparison a fair one, the lowest of the Author's calculated values which excluded the abnormal year 1913-14 should be deleted, but even if this was done the ratio between the values of the required net storage as deduced by the three authorities was still more than 3 to 1.

416. It seemed impossible to escape the conclusion that one of the world's greatest reservoirs was to be built without any agreement among the technical experts, either on the method of calculating the size of the reservoir or on the philosophical approach to Nile control in relation to the national economy.

Mr Aziz H. Labib (Hydrological Engineer, Ministry of Public Works, Egypt) commented on the statement in § 58 that a total over-year capacity of about 21.5 mld cu. m would be sufficient to equalize the inflow of the river as against the 70 mld actually allowed for in the design of the Aswan High Dam (Sadd-el-Aali).

418. Before analysing the assumptions on which the Author had based his conclusions regarding this point, it was important to mention clearly the full significance of the Sadd-el-Aali scheme. It was not only an over-year storage reservoir to allow expansion in cultivation, but also to ensure irrigation requirements for the existing as well as the newly reclaimed areas even in low years or successions of low years. Any deficiency in supplying the land with water in any of those years would greatly affect the Egyptian economy. Another main purpose for constructing the Sadd-el-Aali was to produce the enormous amount of firm electric power necessary for the industrial development.

419. While the live storage capacity of the reservoir would serve irrigation requirements and production of power, another capacity must be added to allow for silt accumulation, and a sufficient capacity must also be allotted to protect Egypt against the highest floods without causing any appreciable damage by the water clarified of silt to scour the river channel downstream of the dam.

420. Survey investigations and study of unavoidable water losses at the selected reservoir area had shown that the optimum live storage capacity which could be obtained was 70 mld. To calculate the possible draught that could be obtained from such a capacity for a series of river flows similar to those recorded at Aswan from 1870 to 1953, Dr Hurst had applied equations (2) and (3) and had arrived at the conclusion that an annual draught of 82 mld cu. m could be obtained. By deducting the mean evaporation,

TABLE 18
(All figures are in milliard cubic metres)

Authority	Method	Irrigation storage (long term)		Additional storage to allow for:				Inclusive total storage		*Evaporation losses: 7½% on:-		
		No evapora- tion allowed for	*Evaporation added (7½%)	(a) sub-annual variation		C sub-total	Silt de- de- posits	Total	E (B + D)	% var.	F (B - A)	Total storage (E)
				(b) flood relief	(a)							
		A	B	% var.	(a)	(b)	C sub-total	D	E (B + D)	% var.	F (B - A)	G
Hurst	Statistical	65	†70	100	22	8	30.0	30	60.0	100	5	9.5
Ahmed	(i) Statistical	‡20	21.5	31	§18.2	8	26.2	30	56.2	60	1.5	5.72
	(ii) Sums of departures: 1899-1953	30	32.2	46	18.2	8	26.2	30	56.2	68	2.2	6.42
	(iii) Departures omitting year 1913-14	9	9.7	14	18.2	8	26.2	30	56.2	51	0.7	4.92
Fathy and Shukry	Deviation curve	41.8	45	64	22	8	30.0	30	60.0	80	3.2	7.70

* The basis of 7½% is clearly only a rough approximation based on Hurst's calculations, and for varying levels is clearly dependent on the area exposed, *not* on volume.

† Draught assumed as 82 out of 92, and then modified for losses by deducting 7½% of contents (130), i.e. 10, giving net draught as 72.

‡ Draught of 72 is stated to give 20 storage by Hurst's formula. The addition of 7½% to allow for losses gives 21.5 total storage required. Derivations not clear.

§ Summer irrigation need is 34.6 and river supply is 16.4; deficit 18.2.

|| Agreed flood storage 8.

and seepage losses appropriate to reservoir contents, a net draught of 72 mld cu. m would be available.

421. However, in applying Hurst's statistical equations, losses had been ignored. It was evident that by allowing for those losses at the High Dam, a greater net draught could be obtained.

422. To illustrate that point a trial regulation had been made over a series of years similar to 1879–1953 after deducting the losses corresponding to the successive accumulated contents. From that regulation a new standard deviation of 15.6 had been derived compared with 19.8 for the case of unaffected natural flow. The average net inflow during the period had been about 81 mld as against an average inflow of 93 mld for the unaffected natural discharge. By substituting in equations (2) and (3) the newly obtained figures for the standard deviation and the average net inflow it was found that the available capacity of the Sadd-el-Aali reservoir (70 mld) would provide a net draught of about 74 mld compared with the 72 mld which had been already obtained from the computations dealing with the unaffected natural river flow.

423. Again, in another trial to find the optimum capacity of the reservoir, investigations had been made by analysing the period of years from 1899–1953, where the discharges of the river were based on actual tank measurements so that their accuracy was beyond doubt. The mean natural flow of the river during that period was only 84 mld. By applying the method of accumulated sums of departures, mentioned by the Author in Appendix I, over that series of years taken in the order in which they had occurred, the result was that a reservoir capacity of 70 mld cu. m would have been needed to guarantee a steady annual flow of 84 mld. Allowing for evaporation and seepage losses, the net annual draught would be 74 mld cu. m.

424. If, however, the sequence of occurrence in that series of years was changed, a matter which could not be ruled out as improbable, a regulation over the sequence 1899–1915, 1939–53, and 1916–38, showed that for a steady annual flow equal to the mean, a greater reservoir capacity of 125 mld would have been needed.

425. It could therefore be concluded that the 70 mld cu. m assigned by the authorities to the live storage of the High Dam was the minimum capacity which could probably guarantee a constant reasonable draught for irrigation demands without causing considerable deficiency in power production for many years.

426. By adding an extra capacity of 30 mld to allow for the accumulation of silt, and another capacity of 30 mld for flood protection, the total reservoir capacity of the Sadd-el-Aali would reach 130 mld.

427. In fact, that practical approach to the problem of the capacity for over-year storage at Aswan had been admitted by all authorities concerned with the plan of development of the river. The optimum capacity of 130 mld cu. m would safely serve all the different purposes for which the High Dam was to be built, including irrigation, power production, flood protection, navigation, fish culture, and other multiple purposes. The reduction in the reservoir capacity suggested by the Author would fail to fulfil those purposes and at the same time would not reduce the cost of the dam to a great extent, since the main cost of the dam was in the construction of the foundations, the upstream and downstream cofferdams, the diversion canal, and in paying the indemnities. The cost of those parts of the High Dam amounted to 75% of the total cost.

428. The practicability of constructing a reservoir with such a big capacity on a sound economic basis had been considered. The optimum height of the dam had been checked by cost-benefit analysis and it was found that the expected increase in the national income, would cover the whole cost of the project in less than 2 years.

429. The Author had considered the reservoir losses as tremendous. In fact, any over-year storage reservoir had to be built in the reach between Aswan and Atbara, where the whole volume of waters of the Nile could be dealt with and all surplus waters could be stored. The unavoidable reservoir losses at the site of Sadd-el-Aali, though large in actual amount, in proportion to the stored water, were less than for any other reservoir constructed in that reach of the river. It was, true that losses would be excessive at the very high level of the lake but the losses in that case would be

advantageous as they would help in getting rid of the excessive flood waters which, if left to escape downstream of the dam, would cause damage to the river-bed by scour.

430. The conclusions arrived at by the Author regarding the seepage losses in the reservoir area were based on inaccurate river discharge estimations. Before the year 1902 at Aswan and 1933 at Halfa those discharges were not obtained from actual measurements but were computed from gauge-discharge curves. Those curves could not be relied upon to determine differences of discharges between the two stations as they represented only a small percentage of the total annual flow of the river.

431. That the flow of the wells in the Western Oasis had increased had been considered by the Author to be due to seepage from the existing Aswan Reservoir. But the method of measuring the flow of those wells had, until 1930, been very primitive. However, if present measurements showed any increase in the discharge of those wells, that would most likely be due to the fact that they were recently re-drilled to greater depths where new water-conveying layers were reached.

432. Permeability in the sandstone formations within the reservoir area was known to be low; that had been confirmed by the permeability tests which were made in 1960 in the Nubian sandstone at Abu Simbel. Again, investigation boreholes in the Oasis of the Libyan Desert had reached granite rock at a depth of 800 m. According to recent information, no serious seepage losses from the new reservoir could be expected.

433. All geologists who had studied seepage thought that the fine clay which remained suspended for a long time in the Nile water would ultimately seal any porous rock in the reservoir basin. That conclusion had been accepted by the Author when discussing infiltration at Wadi Rayan Reservoir. So far as the reservoir bed was concerned, the Author's idea that the deposited silt layer might be removed wholly or partially during flood was not in accordance with the present silt regime of the Nile. The Nile bed in the reach of the Sadd-el-Aali Reservoir was known to silt during times of flood. Scour might take place only at the end of the emptying period of the existing Aswan Reservoir before the flood arrived. With the new regime of regulation by the High Dam the lake would never be emptied below a capacity of 30 mld. In that case it was evident that no removal of any layer of accumulated silt on the bed could possibly take place.

Mr W. H. R. Nimmo (Civil and Hydraulic Engineer) observed that much interesting data had been presented in support of the contention that the serious silt and seepage problems involved in the High Dam project could be avoided and more efficient and cheaper control of the Nile waters achieved by providing annual and over-year storage in separate reservoirs and by eliminating the great losses in the Sudd region. An economic comparison of the two alternatives would be considerably affected by the rates of evaporation assumed, particularly in the case of the High Dam. Although the losses in the swamps were now known, they did not afford any indication of the evaporation from open water. Because of the considerable seepage to and from the reservoir, evaporation at Aswan could not be determined from measurements of inflow and outflow. As stated by the Author, the magnitude of the High Dam project required more elaborate and precise measurements of evaporation than were at present available.

435. In that connexion observations in the arid south-western states of the United States indicated that evaporation from a 12-ft-dia. circular pan sunk in the ground was approximately the same as that from a large water surface.

436. In Australia evaporation was being measured in pans of various types and sizes. The standard pan of the Bureau of Meteorology was a metal tank, 3 ft dia., 3 ft deep, and surrounded by a 16-in.-wide water jacket. The factor to be applied to records from that pan to find the loss from a large reservoir was not known.

437. For the purpose of obtaining comparative results from pans of different types and sizes, there had recently been installed at Kirkleagh, Queensland (latitude: 27° 5' S; longitude: 152° 34' E), a group of pans comprising an Australian standard jacketed pan, a U.S. Weather Bureau, Class A pan, 4 ft dia., 10 in. deep, mounted on a timber support with the bottom of the pan 6 in. above the ground; and sunken concrete pans

having diameters of 3, 4, 6, and 12 ft. The climate was semi-tropical, most of the mean annual rainfall of 40 in. falling during the summer months. The experiment had not yet extended over a sufficient period to yield reliable quantitative results, but analysis of the observations had shown that, apart from the possibility of rain splash, sunken pans were affected by transfer of heat to and from the surrounding soil. Since the thermal conductivity of the soil increased with increase in moisture content, the rate of heat transfer to and from the pan varied throughout the year with seasonal conditions. Because of the lesser ratio of circumference to volume, the effect of rainsplash and transfer of soil heat on a 12-ft-dia. pan would be only a quarter of that on a 3-ft-dia. pan. The U.S. Class A pan was immune to both influences but evaporation from it did not bear a constant ratio to that from open water.

438. Continuous records⁴⁹ of evaporation from 12-ft-dia. pans in the arid climate of Texas were available for the 6-year period 1950-55 for the two stations shown in Table 19.

TABLE 19

	Fort McIntosh	Dryden
Latitude, N.	27° 30'	30° 03'
Elevation: feet	410	2,160
Mean annual temperature: deg. F	74.8	68.3
" " rainfall: inches	12.69	7.75
" " relative humidity: %	54.1	50.7
" " wind speed: miles/hour	3.9	5.3
" " evaporation: inches	86.47	95.52

439. Treating the monthly values from the two stations as one record, it was found that the coefficient of correlation of evaporation E to temperature T was 0.78 and the regression equation was:

$$E = 0.41 T - 21.5.$$

Assuming a mean annual temperature at Aswan of 77°F, ranging from 59°F to 91°F, it appeared that losses by evaporation for the High Dam project might even exceed those given in the Author's Table 13.

Mr A. N. M. Robertson (Consultant, Sir William Halcrow and Partners) was impressed by the wide scope of the Author's contribution to the complex subject of Nile control. Having been formerly associated with its interests when he was Director of the Sudan Irrigation Department, and subsequently Irrigation Adviser to the Sudan Government, he realized that its problems had always offered freedom for diversity of expert opinions. He therefore appreciated the Author's originality of thought, and the case put forward in expressing his ideas.

441. Though not accepting the ideas in their entirety, Mr Robertson was in complete agreement with the Author's opinion that although the High Dam project had been subject to highly qualified expert investigation, the design involved a change from the former conception that Nile control was primarily for the irrigation development of Egypt and the Sudan. It now seemed that its purpose would be mainly for the provision of large-scale hydro-electric power for industry. The absence of silt-free water during the flood season, and the use of such water for irrigating sandy desert land might cause difficulty in future of the nature the Author envisaged, coupled with the prospect that the regime of the Nile throughout Egypt would be affected by scour, and that erosion at the barrages and elsewhere in its course would occur.

442. For the purpose of irrigating about 2 million acres of land, the capital cost of the works did not appear to be economic, and it was hoped that the intended industrial development would succeed in meeting the cost for the benefit of Egypt.

443. Appendix I afforded a fuller opportunity of examining the conditions of the annual discharges of the Nile downstream of Aswan in continuation of the information Mr Robertson had contributed to Morrice and Allen's 1959 Paper⁵⁰.

444. The Appendix gave the discharges during the 20th century from 1899–1900 to 1953–54 exhibiting the records in hydrological periods more definitely than they had been given when stated for calendar years, and the cyclic periods referred to in 1959 were now compared with those obtained from Appendix I of the Paper.

445. The results were contrasted in the manner shown in Tables 20 and 21. The terms "southerly" and "northerly" were derived from Colonel Rawson's Paper⁵¹, when he discovered the fact of those cyclic changes in the discharge of the Nile and drew attention to them.

TABLE 20.—9-YEAR SOUTHERLY CYCLES

Cyclic periods in calendar years as stated in 1959		Cyclic periods in hydraulic years according to Appendix I of Dr Ahmed's Paper	
	mld cu. m		mld cu. m
1899–1907	81	1899–1900 to 1907–08 . .	79.3
1918–26	81	1918–19 to 1926–27 . .	79.3
1937–45	78	1937–38 to 1945–46 . .	75.9
Mean value	80	Mean value	79.5

TABLE 21.—10-YEAR NORTHERLY CYCLE

Cyclic periods in calendar years as stated in 1959		Cyclic periods in hydraulic years according to Appendix I of Dr Ahmed's Paper	
	mld cu. m		mld cu. m
1908–17	88	1908–09 to 1917–18 . .	89.5
1927–36	86	1927–28 to 1936–37 . .	85.0
1946–55	87	1946–47 to 1955–56* . .	87.0
Mean value	87	Mean value	87.5

* The annual discharges for 1955–56 were taken from the November 1959 Statement, being calendar-year discharges kindly supplied by Dr Hurst.

It would be observed from Tables 20 and 21 that there were only slight differences in the mean values as the result of either method of comparison.

446. Figs 18, 19, and 20 showed the effect of contrasting the series of 9-year southerly periods with the 10-year northerly periods during the 20th century. Fig. 18 illustrated the cyclic period of discharges downstream of Aswan; it was prepared from the data given in Appendix I, for it seemed desirable to learn to what degree the annual discharge in the cycles compared with those for similar cycles of the series during the 20th century, and Figs 18, 19, and 20 illustrated those comparisons. As a result it was considered that although there were considerable differences in the discharges of corresponding years of the cycles there was what might be considered to be a general pattern for the course of a cycle. For instance, in the northerly cycle the average value during the first 3 years was above the mean of 87.5 mld followed by 5 years during which the

FIG. 19.—THE ANNUAL DISCHARGES OF THE BLUE NILE AT ROSEIRES IN RELATION TO THE CYCLIC PERIODS WHICH HAVE OCCURRED DURING THE 20TH CENTURY

FIG. 20.—THE ANNUAL INFLOWS OF LAKE TANA IN THE CYCLIC PERIODS WHICH HAVE OCCURRED DURING THE 20TH CENTURY

discharges were below that mean value. It appeared that the record low-discharge of 1913–14 was not discordant with that outline and the concluding years of the cycle had high discharges over the mean value of 87.5 mld and it was believed to be remarkable that the mean value of the cycle had been sustained in that summer.

447. The southern cycle had a similar period of high discharge in the early years of the cycle with a second period during the middle of the cycle, while subsequently the latter half of the cycle had variations near the mean value of 79.4 mld cu. m for such cycles. The current period of discharges was in a southerly cycle from 1956–57 to 1964–65, and it would be interesting to note to what extent the annual discharges would conform to the general pattern, and to what degree they would resemble the outline of one of the three previous cycles which had occurred with 19-year intervals between the occurrence of corresponding discharges.

448. Figs 19 and 20 gave supplementary information of a similar nature relating to the Blue Nile at Roseires and to Lake Tana. They were based on the calendar data used for the figures which illustrated the information given during the discussion on Morrice and Allan's 1959 Paper⁴⁴, but as already experienced in the comparison made for the discharges at Aswan there would be little difference from a hydrologic year record at those sites.

449. The Roseires discharges were of special importance, showing the cyclic changes clearly at a site which was the main source of the Nile floods.

450. There was a difference of 6 mld between 53.2 mld of the mean discharge during the northerly cycles and 47.2 mld during the southerly cycles.

451. The results at Lake Tana were also of interest as it was the source of the Blue Nile. Detailed accounts of all the discharges in each cycle had been prepared and could be supplied if required.

452. It was represented that that record of periodical variations in the series of annual discharges was an addition to our knowledge of the hydrology of the Nile. They were for relatively long periods in the series of annual discharges which had hitherto been taken as having an average value of 83 mld cu. m; and it seemed that such variations were due to be taken into account when planning for over-year storage.

Mr Y. M. Simaika (Technical Adviser, Ministry of Public Works, Cairo) drew attention to some incorrect statements in the Papers. For example, in § 226 the Author had quoted Ball as saying that land on both banks of the river was being irrigated from wells whose water levels were higher than those of the river. What Ball had actually written was that the water in the one well to which he levelled was 0.50 m below that in the river⁵².

454. There could be no doubt about the height of the many big floods which had occurred from 1870–98, since their levels were recorded on several gauges in Egypt, and there were records of the Nile banks being breached with great damage to life and property⁵³. Also, no other explanation was possible than that they were due to heavy rainfall in Abyssinia. The statement in §§ 207 and 220 that there was an isolating layer between river-water and ground-water, which was washed away in flood time (and presumably restored later) was entirely supposition and contrary to the evidence. Along its banks for long distances the river was in contact with sandstone. The bed of the river was sandstone overlain by Nile deposit, of which the surface material was a mixture similar to that which formed the bed below Aswan, and similar to but rather coarser than that carried in suspension. During the flood season, from July to the end of October, the mean velocity over the cross-section of the river was greater than 1 m/sec, and the bed was continually being moved. The water which came down after October contained only 3% of the total material carried in suspension of which one-third would be clay with a concentration of about 30 p.p.m. as against 800 at the top of the flood. The velocity was still high enough to carry most of that fine material in suspension, which, however, would deposit in calm water in the reservoir. The deposit would be increased in the High Aswan Reservoir.

455. The Author's argument in § 58 regarding the capacity of the High Aswan Dam was fallacious. According to Hurst's theory on long-term storage, and from his equation $\log_{10} S/R = -0.08 - 1.05 \frac{M-B}{\sigma}$, the draught (B) that could be *annually* maintained

by a storage (S) included the losses (L) in the reservoir. It was evident from the above equation that a loss (L) could not be *annually* compensated by a capacity ($S+L$).

456. It should be borne in mind, however, that the High Aswan Dam would be a multi-purpose reservoir:

- (a) to guarantee the biggest annual quota to meet future irrigation requirements;
- (b) to produce the biggest possible hydro-electric power; and
- (c) to protect Egypt against the danger of the highest floods thus reducing the spilling of clear water and the possible degradation downstream.

All those required the reservoir to be as large as possible up to the limit when the losses became excessive^{54, 11}.

457. A reduction in the capacity would reduce the cost by only a small amount since the main cost of the High Aswan Dam would be in the construction of the cofferdams, diversion channel, grout curtain cut-off descending to bedrock, etc.

458. Hurst had shown¹⁰ the difficulty of operating an over-year storage reservoir and it would be realized that the reservoir with its assigned capacity for live storage of 70 mld, a capacity much less than the mean, could by no stretch of imagination be considered too large.

459. Referring to storage losses in the Aswan Reservoir, Mr Simaika said that the gains and losses between Halfa and Aswan as deduced by the Author could not possibly be true.

460. In the period 1890–1902 the figures for the discharges were based on a general discharge curve drawn from observations taken at a later period⁵⁵. Since there were several very high years in that period it was found necessary to extrapolate the curve. Thus the discharge derived from those curves could never be anything but a very rough approximation in the absence of direct measurement.

461. As an illustration of the reliability of gauge discharge curves, the mean curve drawn from all observations (1921–51) at Roseires could be used, this being one of the best discharge sites in the whole Nile system. The scatter of individual years was very large and in extreme years like 1921 and 1951 showed departures from the mean gauge-discharge curve of about 50% high in 1921 and low in 1951⁵⁶.

462. Those variations were of course caused by continuous, alternating scouring and silting in the bed.

463. Gauge-discharge curves were therefore useless for measuring such small differences as losses or gains on the Nile.

464. The only explanation of the apparent gains and losses found by the Author was that they were entirely caused by departures from an extrapolated gauge-discharge curve constructed for a totally different period and therefore could not possibly be real.

Dr A. D. Lewis (former Director of Irrigation, South Africa) referred to the question of the safety of the design of the High Dam, mentioned in § 103. A flood resulting from a failure of the dam would sweep through the Nile Valley, in which the majority of the Egyptian population lived. It could be assumed that the Author had asked the question only after earnest consideration, but with an intimate knowledge of the local conditions. Without that knowledge Dr Lewis would not criticize the design adversely beyond saying that in the course of his experience he had turned down a number of somewhat similar designs in favour of concrete dams.

466. The Author's Wadi Rayan scheme was a modified and enlarged version of Willcocks's scheme of 1894, described in his book "Egyptian Irrigation"⁵³ with an appendix by Dr Schweinfurth. The enlargement had been made possible by the building of the electric power plant at Aswan. The chief fears in regard to the scheme were

that damage might be caused to the existing cultivation in the neighbouring Fayoum depression by seepage from water standing high in the Wadi Rayan depression and possibly carrying harmful salts partly concentrated by evaporation in the reservoir. The Author had not regarded that as a serious danger (§ 109) and had referred to a report by Sir Cyril Fox¹⁴, to which Dr Lewis had not had access. Could a short summary of that report be furnished? Without this report Dr Lewis still had lingering fears that silt would not do all that the Author expected in checking seepage.

467. One of the big problems was to pass, with as little loss as possible, an annual entry of more than 40 mld cu. m of water through the Sudan Basin for about 1,700 km from Bor to Khartoum, with a very flat slope, averaging about 1 in 38,000 and falling to 1 in 58,000 in the last 1,000 km above Khartoum (§ 106). The Author's solution, or partial solution, by hydro-electric pumping was an ingenious one, but was there not a possibility that the very high rate of pumping into the White Nile would cause an afflux which would push much of the water back into the swamps again unless the banks of the river were raised on a large scale?

468. The Author seemed to have made out a good case for building the series of dams in the reach between Wadi Halfa and Abu Hamad as early propositions (§ 184), pending further investigation into the larger schemes at Aswan, Wadi Rayan, and in the Sudan swamps.

Mr A. E. Griffin (Consultant) said the Paper covered a very wide field of Nile management, raising several points that had been controversial for years. Admittedly the loss of silt (§§ 15-23), as a result of storage conditions in the High Dam, would be an adverse factor to a limited extent. But how far had the importance of silt from the agricultural aspect really influenced Nile dam design? It was Mr Griffin's impression that the only reason for the traditional design was to prolong the useful life of the dam. Had that policy not been pursued, both the relatively small Aswan and Sennar Dams would have been useless for storage purposes by now. On the other hand, the High Dam should have a useful life for 500 years or so. Moreover, even under High Dam conditions there was likely to be fine silt in suspension which would find its way to the fields. In due course, some means of keeping the heavier silt in suspension for selected periods was sure to be devised and put into effect if such measures were found to be profitable.

470. The Author's method of stating how the shares were arrived at (§ 94) in the recent water agreement tended to be confusing and might be clarified as shown in Table 22.

TABLE 22

	Milliards of cubic metres at Aswan (approximations)		
	Egypt	Sudan	Total
Average annual flow			84
Present uses	49*	4	53
Balance remaining			31
Share of balance.	16.5	14.5	31
Total share	55.5	18.5	84

* Not including Gebel Aulia evaporation losses.

It could be seen from the Table that if allowance was made for river losses upstream and downstream of Aswan, the unused balance seemed to have been more or less equally divided.

471. Egypt, however, must have elected to earmark 10 mld of her share of 16.5 mld to meet estimated evaporation losses from the High Dam Reservoir. The Author had

deplored that and had implied that it was going to be a dead loss which, surely, was not the case. In return for the evaporation losses, the High Dam scheme, when fully developed, would provide a power potential for Egypt of about 8,000 million kWh in an average year at low cost. In addition, it would greatly improve the performance of the recently completed Aswan power station by almost doubling the firm power output. Economic studies carried out by the World Bank based on careful forecasts of the growing power demand in Egypt, had revealed that the energy from the High Dam and other sources would be fully and efficiently exploited within the next 15 years or so with much advantage to the general economy of Egypt as a whole. To provide the equivalent power from thermal stations would yield a much lower benefit on investment. Moreover, it should be remembered that all alternative storage schemes would be subject to evaporation losses.

472. Having been involved with the Merowe studies (§ 92) some years ago, as his colleague, Mr Gerald Lacey, was with those of Wadi Rayan (§ 88), Mr Griffin appreciated the merits of both schemes but, separately, or integrated with storages further upstream of Aswan, they would not be so broadly beneficial to Egypt as would the High Dam project. According to the Author's method of operating Wadi Rayan (§ 119) it seemed that expensive generating and pumping capacity would be lying idle for long periods. If that was the case, it was hard to believe that the operating costs could be kept down to 3 mm/kWh having regard to investment charges.

473. The Author's proposals for dealing with White Nile swamp losses were of great interest and appeared to have considerable merit. The Jonglei scheme, selected after 50 years of patient, plodding study, was dispensed with. In the circumstances it seemed that the logic was sound for, as it had turned out, the ruling factor in shaping the solution was the problem of the Bahr el Ghazal losses and not those of the Bahr el Gebel. The latter had received nearly all the attention till recently. The computed losses were about equal in both river systems, but those in the Bahr el Ghazal, by reason of the local topography, could only be dealt with by pumping. Hence, if a hydro-electric pumping installation must be provided for one swamp, practically the same basic installation could handle the losses in the other also, and the Jonglei gravity scheme would become unnecessary. The point arose, however, whether it would be possible to recover 12 mld from the Bahr el Ghazal swamps at a satisfactory benefit-cost ratio in view of the amount of river remodelling that might have to be carried out. Assuming the full 12 mld could not be recovered, or at least was a matter of conjecture, it would be necessary to investigate the minimum volume of recovery that would justify the execution of the Author's scheme and the dropping of the Jonglei gravity scheme.

Sir Harold Hartley (Scientific Adviser, Constructors John Brown Ltd) wrote that he had gone to Egypt in 1914 to study irrigation, since when there had followed the developments in the Nile Valley, to which the Author had made such a valuable contribution. He had made out a strong case for re-consideration of the design of the High Dam before it was too late. Sir Harold was particularly impressed with his arguments on the effects of the deposition of silt in the reservoir and silt trap both as regards the loss of its valuable contribution to the sandy soil of the areas to be brought under cultivation, and the effect of the scouring of the river channel by silt-free water. His arguments about the different equations which gave varying dimensions for the High Dam surely deserved further consideration by the experts. That applied also to the Author's interesting proposal to use the Wadi Rayan depression for over-year storage. In that connexion the Author had raised the question of loss of water by seepage and he had touched elsewhere on the underground movement of water, the great unknown in so many hydraulic projects. That was a field in which further investigation was badly needed.

475. In connexion with the serious loss of water by evaporation from reservoirs in tropical countries there was no mention in the Paper of the successful experiments carried out by the Commonwealth Scientific and Research Organization in Australia on the use of monomolecular films of hexadecanal, introduced in 1948 by W. W.

Mansfield, for the control of evaporation. Dr F. W. G. White, the Chairman of C.S.I.R.O., had described the results of those trials at the meeting of the World Power Conference at Madrid in 1960⁵⁷. Savings of one-third of the evaporation had been obtained in a large-scale experiment on a reservoir at Broken Hill in New South Wales where the normal annual evaporation was about 70 in. (178 cm).

476. Finally, the long-term solution of the Nile water problem which was of such vital importance to the crowded inhabitants of the Nile Valley must lie, as the Author had pointed out, in a project to eliminate the loss of water by seepage and evaporation in the Sudd so that the immense storage capacity of the Great Lakes could be used efficiently. This was surely a project that called for international co-operation.

Mr Edward Gruner (E. and G. Gruner, Basle, Switzerland) said the Author had shown that the immense ground-water-table of the Libyan Desert discharged into the Nile. Fig. 13 indicated two thalwegs in that aquifer. One led from Farafra Oasis to Qattara depression. The other followed the Nile Valley and diverted through Wadi Rayan to Qattara depression.

478. In Upper Egypt flow lines of that aquifer converged on the river, which indicated that it was fed by ground-water. In Lower Egypt flow lines crossed the river, which indicated that the ground-water was fed by it. Such conditions were more apparent on the Oronte River in the Syrian Province. Its regime was controlled during the dry season by large underground reservoirs. The discharge of that aquifer occurred from a group of sources between the Lebanon and the Anti-Lebanon with approximately 13 cu. m/sec, and from fifty sources in the El Ghab depression, with approximately 15 cu. m/sec. Most of the latter were fed by the ground-water-table which underlay the plateau between Hama and Aleppo where precipitations were between 400 and 250 mm/year. Such a subsoil reservoir was most economical because its losses were small and its discharge was regular. The old irrigation of Persia had made use of those facts and had drained such water-tables through "kanats".

479. The Author had assumed that reservoir losses diminish owing to silting until they reach a firm value. River-beds were generally considered to be watertight since in many instances the ground-water-table was below the surface-water level. In the Rhine Valley a ground-water stream followed the pre-glacial thalweg now covered by alluvium. It even crossed the river. Following the construction of the first sections of the Grand Canal d'Alsace near Basle the orchards on the German shore were slowly dying, as displacement of the surface flow had disturbed its natural balance with the subsoil flow. Therefore, in all remaining schemes above Strasbourg the head and tail water of power stations had to be left in the existing river-bed, except for a short stretch near the power house.

480. Professor Hellstrom's laboratory tests had shown for Nubian sandstone a velocity of water of some metres per year. That was in contradiction to the rapid increase of discharge in Kharga Oasis after the filling of Aswan Reservoir in 1902. It seemed that by mistake the factor of impregnation of rock was applied for the phenomena of percolation through rock. Seepage losses followed cleavages, which explained the short time required by the water to travel over 240 km to Kharga Oasis. There were no means to predict percolation losses of any new reservoir, except through the method of trial and error. Such a trial was made with the Montejaque Reservoir in Spain, which failed owing to a total loss of the water impounded.

481. With an annual average of only 29 mld cu. m left for further irrigation development in the Nile Valley, optimal use should be made of that volume. That water being a rare commodity, it was even justified to pay an elevated price for its over-year conservation. The Wadi Rayan depression was close to the area of consumption, thus reducing transport losses after storing, and it offered a basin surrounded by ground-water, so that it would be fed by seepage. The use of pumps for lifting discharges had some disadvantages. The alternative would be an adaptation of the historic kanat by building a system of canals and tunnels over the Fayoum depression and through the plateau of Giza to the Delta barrage.

482. The Author had quoted in § 104 the recommendation of an international commission, saying that in case of hostile action the water level in Sadd-el-Aali must be lowered to R.L. 150 m, or, in view of atomic bombs, to R.L. 130 m. In view of such an action the risk to be run with several reservoirs of reduced size was smaller. The flood released by breaching one smaller dam would be less destructive and could even be retained by the lowest reservoir if empty.

483. It was a gigantic task to concentrate the irrigation water of Egypt in one reservoir. The fate of the majority of the Egyptian people was linked to that scheme. The alternative shown by the Author would better harmonize with the natural balance of water in the Nile Valley.

The Author, in reply, said that in the first Paper he had endeavoured to cover the whole subject of Nile control, and to deal especially with recent developments. In the second Paper he had given the results of the investigation he had carried out himself on the storage losses in Aswan Reservoir, and their relation to ground-water.

485. The Aswan High Dam was the main topic. In the first place it was considered to give a complete solution to the problem of Nile control, and to provide Egypt and the Sudan with the maximum possible volume of water for the expansion of cultivation. Secondly, its reservoir capacity was about the largest conceivable anywhere in the foreseeable future. Thirdly, it embodied a departure from the time-honoured irrigation policy hitherto followed, that dams erected in the Nile should not interfere in any way with the free passage of silt-laden water, so that this should continue to enrich the soil of Egypt and to make good any loss of fertility, and to form new soil from the sandy desert land for the future expansion of cultivation.

486. The High Dam was essentially for over-year storage and would therefore form a permanent lake in which all or almost all the silt brought down by the river would be deposited, amounting to about 134 million tons/year. Not only would this deprive Egypt of a valuable fertilizer, but the silt-free water which emerged from the dam was bound to cause erosion in the river-bed, and might undermine permanent structures on the river.

487. In § 81 he had given the results of an experiment which had been carried out at Aswan Reservoir. The silt concentrations had been measured before entry to the reservoir, and at the outlet, and also at the Delta Barrage near Cairo. The result had shown that the relatively clear water emerging from the dam had picked up from the river-bed about a third of what it had deposited in the reservoir.

488. It had been shown in the Paper that all the trouble arising from silt deposition and erosion could be avoided if the reservoir was placed in a detached position away from the river stream, so that only the silt content of the water actually stored would be deposited in the reservoir. He had selected Wadi Rayan depression which was admirably suited for that purpose.

489. The main features of the High Dam discussed in the Paper were, first, its reservoir capacity, and secondly, the losses incurred in it. In the official report¹¹ a statistical formula which had been devised for connecting the capacity of an over-year reservoir with the draught it maintained was applied for the first time to determine the capacity of the High Dam Reservoir. The question whether or not such a formula should be applied to the High Dam had been discussed in the Paper. First, such a general rule which covered many physical phenomena including river discharges, rainfall, temperature, and pressure variations, as well as annual tree rings and varves in lakes could not be expected to give accurate results when applied to individual cases like the High Dam. Secondly, it was premature to establish such a general rule for application to all reservoirs that were likely to be met with in practice, and to apply it for the first time to the High Dam Reservoir which was the largest conceivable anywhere. The contention was that it was of such importance and magnitude as to merit independent study in which local conditions as well as economic and other factors should be taken into account.

490. Assuming, albeit, that such a general formula was applicable to the High Dam the next step was to investigate how it was applied, and this was a crucial point in this subject. The theory on which that statistical formula had been based had presumed that there were no losses in the reservoir, or else they were compensated by rainfall as at Lake Victoria. The High Dam, on the contrary, involved heavy losses. That difficulty was overcome in the official report by assuming that the draught emerging from the reservoir was equal to the net draught plus the losses, and the over-year capacity was calculated on that assumption and taken as that required to maintain an outflow of the net draught plus losses. It was shown in §§ 54-57 that that conception was wrong.

491. The inflow at the upper end of the reservoir might be considered to be made up of two separate parts: first, the draught which emerged from the reservoir, and secondly, the losses which were dissipated in it. The former was a variable quantity for which an over-year capacity was needed to store up excess in order to make up the deficit, and so even out the draught. That was a case where an over-year capacity was needed to maintain a constant draught. The losses on the other hand were practically constant within the limits of normal regulation levels, and so did not require such an over-year capacity as was needed to smooth fluctuations in net draught.

492. Calculated by the erroneous method described above (using formula (3), § 51) the over-year capacity came out much larger than actually needed and was given in the official report as 70 mld cu. m. It was stated that this capacity would ensure a draught of 82 mld, less losses which were estimated as 10 mld, giving a net draught of 72 mld. In addition, 30 mld cu. m were allocated to annual regulation and flood relief and 30 mld cu. m to a silt-trap, making the total reservoir capacity of the High Dam as 130 mld cu. m.

493. The method proposed in § 58 for dealing with losses was to calculate separately the capacity necessary to maintain a net draught of 72 mld emerging from the dam, using the same statistical formula ((3), § 51). This gave an over-year capacity of 20 mld cu. m. To this must be added the capacity necessary to accommodate the losses while they were being dissipated into the reservoir, calculated at the accepted rate of 7.5% of the storage, which would give 1.5 mld cu. m, making a total of 21.5 mld cu. m against 70 mld cu. m given in the official report. Actually, 1.5 mld cu. m was a little too much but was retained since the rate of evaporation was variable throughout the year. If these results were correct, and the Author had every reason to believe that they were, both from a theoretical and practical point of view, they would invalidate the whole design of the High Dam. There would be not only a considerable reduction in the capacity, but also a large decrease in the losses.

494. This brought him to the second point which was the subject-matter of the second Paper. The losses were bound to be large because the capacity was large. The two naturally went together. Only evaporation, however, had been taken into account in the official report, while seepage was ignored altogether¹¹. No one knew of any reservoir in the world where there was no seepage.

495. Moreover, in calculating evaporation losses, readings of rates of evaporation which were taken 30 or 40 years ago by primitive methods were made use of, whereas for a project of this magnitude, field tests should have been made over the entire water-surface of the reservoir, in order to get a real indication of what the evaporation losses were likely to be. Besides, these readings were taken at the water level of the Nile, whereas the storage level in the High Dam Reservoir would be about 100 m higher. The higher the level the greater would be the wind velocity and the greater the rate of evaporation. It was shown in § 265 that the rate of evaporation in the High Dam Reservoir would be about 40% higher than that calculated from readings which were taken at the level of the Nile.

496. With regard to seepage the Author drew attention particularly to the results of an analysis of the losses which had been carried out independently by the Government consultants and himself. The losses in Aswan Reservoir were analysed for the period 1921-52. This period had been chosen because the discharge readings both at

Aswan and Wadi Halfa were considered to be fairly accurate. Table 23 gave the results of the calculations made by the consultants in their official report. That interval was divided into two separate periods, 1921-33 when the reservoir capacity was 2.5 mld cu. m, and 1934-52 when it was 5 mld cu. m. Only the first period would now be considered. The mean annual loss calculated from the Table for this period amounted to 0.63 mld cu. m or about 25% of the reservoir capacity. This agreed with the Author's results given in § 219.

497. Taking 25% of 130 mld cu. m the annual loss in the High Dam, by analogy to Aswan Dam, would amount to 32.5 mld cu. m. The mean discharge of the Nile was 83 mld cu. m, the remainder after deducting the above losses amounted to 50.5 mld cu. m which was about 1.5 mld cu. m less than what Egypt and the Sudan were getting together at present. This result was conclusive in demonstrating the enormous losses that were likely to take place in the High Dam scheme annually during the period of

TABLE 23.—ANALYSIS OF LOSSES IN ASWAN RESERVOIR*
Million cubic metres

Years	Loss	Departures	Squares
1921-22	0	-500	25
1922-23	800	300	9
1923-24	-800	-1,300	169
1924-25	-700	-1,200	144
1926-27	100	-400	16
1927-28	1,600	1,100	121
1928-29	1,400	900	81
1929-30	1,800	1,300	169
1930-31	500	0	0
1933-34	1,600	1,100	121
	6,300		855
1934-35	1,500	1,000	100
1935-36	800	300	9
1936-37	700	200	4
1937-38	800	300	9
1938-39	1,000	500	25
1939-40	0	-500	25
1940-41	-100	-600	36
1941-42	700	200	4
1942-43	-500	1,000	100
1945-46	1,100	600	36
1947-48	-100	-600	36
1948-49	-400	-900	81
1949-50	800	300	9
1950-51	-800	-1,300	169
	5,500		643
	6,300		855
	11,800		1,498

$$N = 24 \quad \text{Mean loss} = \frac{11,800}{24} = 500.$$

$$\text{Probable error} = \frac{2}{3} \sqrt{\frac{1,498}{24 \times 23}} = \pm 110.$$

Hence, mean loss = 500 ± 110 million cu. m.

* Note: for further details see Table 24, p. 391 onwards.

20–30 years after its construction. Naturally, the losses in Aswan Reservoir were greater during the previous 20 years. The fact that they could not be measured because the discharge readings at Halfa were unreliable was no reason for ignoring them. They were bound to be larger, likewise in the High Dam scheme during the corresponding period.

498. The Author then referred to Fig. 10 and drew attention to the large quantity of water which the river was receiving from underground sources before the erection of Aswan Dam, since the water-table was substantially higher than the water level of the river even in flood time. After its erection there were alternate gains and losses, since the water-table was about the same as the mean annual water level in the reservoir. Since the first heightening was completed in 1912 there was generally a loss from the river with an occasional large gain or loss. This was particularly marked by the large gain which took place in 1916, followed by a large loss in 1918. Afterwards the gain had diminished, and the loss had prevailed and become more steady as time went on.

499. Fig. 13 gave the contours of the water-table which had confirmed the test results obtained by the Author regarding the exchange between river and ground-water (Fig. 10). The theory developed by the Author was then used to explain the large difference between the mean Nile discharges during the 19th century and that during the 20th century. It showed that it was not a mere coincidence that the building of Aswan Dam at the beginning of the 20th century marked the difference between the period of high discharges of the 19th century and that of low discharges in the present one; the dam had deprived the river of a large gain of ground-water and in addition the river lost a considerable volume of its own water, some of which had re-appeared as increased discharge in the Great Oases.

500. It was convenient to deal with the contributions to the discussion under the following six headings:—

- (1) Capacity of the High Dam Reservoir.
- (2) Losses likely to be incurred in it.
- (3) Silt problems.
- (4) The Wadi Rayan project.
- (5) The pumping scheme for the reduction of losses in the Sudd region.
- (6) Miscellaneous comments.

In a few cases where the contributor was not mentioned specifically, the reply was included with that he had given to other contributors for the same or similar questions.

Capacity of the High Dam Reservoir

501. With regard to the reservoir capacity in the High Dam scheme, mentioned by Mr Simaika in § 455, the Author emphasized that in § 58 he had merely concluded the arguments given in §§ 52–57 which had asserted that losses were actually abstracted from the inflow and dissipated in the reservoir before the outflow left it, so that the conception of augmenting the outflow by the losses which never emerged from the dam was basically wrong. This was what Mr Simaika had called fallacious.

502. Referring to Hurst's equation (3) in § 51:

$$\log_{10} \frac{S}{R} = -0.08 - 1.05 \frac{M-B}{\sigma}$$

Mr Simaika had written that the draught (B) that could be maintained by storage (S) included the losses (L) in the reservoir, and that it was evident from the above equation that a loss (L) could not be annually compensated by a capacity ($S+L$).

503. Mr Simaika had obviously overlooked the Author's argument that the losses (L) should *not* be added to the outflow (B), since they were of different nature. The outflow was a variable quantity dependent on the inflow. It therefore required an over-year capacity to store up excess in order to make up the deficit, and so even out the draught. The losses were practically constant and so did not require an over-year capacity such as was required to smooth the fluctuations in the outflow. These two

dissimilar quantities could not, therefore, be added together and an over-year capacity found for them both. This explanation should show Mr Simaika where the fallacy was, and on whose side.

504. Mr Black had said in § 364 that in order to demonstrate his remarkable insight into Hurst's statistical approach the Author had managed to reduce the capacity by half by eliminating the year 1913–14.

505. The Author had made no suggestion of eliminating the year 1913–14 when he demonstrated in §§ 52–58 that the method used by Hurst and Black for taking account of the losses was at fault, resulting in the highly exaggerated over-year capacity of 70 mld cu. m. He had shown that by a correct application of Hurst's formula the over-year capacity should be reduced to 21.5 mld cu. m, so that the year 1913–14 did not come into the picture at all. The suggestion of eliminating the year 1913–14 did not appear in the Paper until later, in §§ 66–69, in connexion with the Wadi Rayan project which had nothing to do with Hurst's formula and the connection introduced in it by the Author.

506. The above reduction of over-year capacity from 70 to 21.5 mld cu. m had obviously reduced the total capacity by the same amount, that is, from 130 to 81.5 mld cu. m. This was further reduced to 65.2 mld cu. m, (§ 76), partly by the elimination of the year 1913–14 (§ 67), and partly by reducing annual storage (§ 75). Hence the bulk of the reduction had been brought about by the Author's correction of Hurst's formula and to a much smaller extent by the elimination of the year 1913–14 which Mr Black had said was responsible for all the reduction.

507. Did Mr Black really believe that Hurst's formula actually covered the year 1913–14, which he thought the Author had eliminated from it? If he did he could not have grasped the meaning of that formula and the statistical approach on which it was based. In that formula it had been assumed that large and small events did not occur, so that the year 1913–14 with its abnormally low discharge was automatically precluded.

508. This had been demonstrated in § 59 where, by using the method of continued sums of departures given in Appendix I, it was shown that in order to maintain a draught of 72 mld cu. m for the period 1899–1953, including the year 1913–14, an over-year capacity of 30 mld cu. m was needed. Whereas by the application of Hurst's formula as amended by the Author's correction for losses, an over-year capacity of 21.5 mld cu. m only was needed which was 8.5 mld cu. m less than that required to cover the year 1913–14.

509. Mr Black, however, must have believed that Hurst's formula covered the year 1913–14, because of the wrong method used in taking account of the losses which produced an exaggerated capacity of 70 mld cu. m for a draught of 72 mld cu. m which would not only cover the year 1913–14 with its lowest discharge of 42 mld cu. m, but a year with practically no discharge at all.

510. Finally, it would appear that both Mr Black and Mr Simaika had failed to perceive the significance of the Author's correction to Hurst's formula. Dr Hurst himself had made no comment on this correction although it invalidated his estimate of the capacity of the High Dam Reservoir on which the whole design of the dam was based, and upon which, in turn, the fate of Egypt, for good or ill, would depend.

511. Without producing one item of evidence to substantiate his statements, in § 363, Mr Black, had devoted much time and space in his comments to analysing the Author's statement that both the High Dam and its rockfill type of construction had arisen from fanciful ideas which were foreign to Egypt and at any rate constituted a departure from the time-honoured irrigation policy (§§ 365 *et seq.*).

512. It was true that dams constructed in the Nile must allow a free and unrestricted passage to the silt-laden water, so that it might continue to enrich the land. But this was only one item of that policy. Another item had provided that dams erected on the Nile must rest on solid rock. There were several sites, particularly at the various Cataracts, answering to that description. This rule had been observed in the Aswan Dam built on granite at the First Cataract, and in respect of Merowe Dam at the Fourth

Cataract which was ready for execution, as well as Semna Gorge at the Second Cataract which was almost ready for execution. On the contrary, the High Dam, the greatest of them all, was to be rockfill erected in a U-shaped section of the river, 200 m deep, filled with products of erosion containing coarse sand, gravel, silt, and clay with isolated boulders of granite. A worse site would probably be difficult to find anywhere for building a dam, whether rockfill or concrete. Was not that fanciful enough?

513. Again, in order to meet those exceptionally unfavourable conditions, intricate and actually labyrinthine operations of clay and cement injections were to be carried out into the depths of that conglomeration of overburden at almost prohibitive cost, with only those vague guarantees mentioned in §§ 103–104. Yet admittedly they were about the maximum that any engineer could have given under the circumstances, in contrast to a concrete dam with built cut-off extending down to the rock foundation.

514. A third item in that established irrigation policy, which was in fact a corollary of the first doctrine, was that any increase of water supply without a corresponding increase of silt was of doubtful benefit. This would apply to the silt-free water to be provided by the High Dam, which would certainly be of doubtful benefit, as shown in §§ 15–21.

515. Moreover, according to that time-honoured policy, Nile control was primarily for irrigation purposes, to which power generation had always been subordinated. Observation of that rule, though it was no doubt overdone, had withheld power generation from Aswan Dam for many years, on account of the dispute which had arisen between the electrical engineer who, in order to increase the firm power, had wanted to raise the water level in Aswan Reservoir during the flood season, to which the irrigation engineer had objected for fear of silt deposit in the reservoir⁴ (§ 26). Yet at the High Dam all the benefits of the silt and precious Nile water lost in storage were sacrificed to power generation, which, at best, could not compensate for irrigation water in a pre-eminently agricultural country. Power could always be generated in thermal stations at a cost which was comparable with that of water power generated from the High Dam, or any other water power scheme on the Nile.

516. It was mainly disregard of fundamental issues of that established irrigation policy which had set the Author against the High Dam scheme from the outset as mentioned by Mr Black in § 365.

517. With regard to the fanciful ideas to which he had referred, the Author gave them below, together with the reasons which had led him to make that statement.

- (a) A statistical formula which had been devised to cover every conceivable physical phenomenon for the determination of reservoir capacities of all descriptions, had been applied for the first time in its history to the largest reservoir ever conceived anywhere in the world, and probably the most costly, ignoring all local and economic conditions. Surely no engineer should be prepared to apply such a general rule to a scheme of that magnitude before it had its trial run and proved its worth in practice. Nor could he afford to ignore local and economic conditions. One of the contributors had said that "that statistical heresy should be cast away because he thought it hid more than it revealed" and was gratified that the Author had "diverted the Nile from the statistical netherworld through which it had apparently flowed for so long" (§ 318).
- (b) The theory on which that formula had been based had involved the assumption that losses in the reservoir were negligible, and its author had declared that even if there were the capacity at Aswan, this district would be unsuitable for the High Dam on account of heavy losses as mentioned in § 42. That was the corner-stone of that theory, yet Hurst and Black recommended the erection of the dam in that district, and in order to overcome the difficulty of heavy losses they had included them in the outflow with the net draught and had obtained a highly exaggerated figure for the reservoir capacity.
- (c) From a practical viewpoint the High Dam was a colossally fanciful idea. In

order to guard against the recurrence of the lowest year, 1913–14, with its deficit of 30 mld cu. m or an equally unfavourable succession of low years, a reserve of 130 mld cu. m had been provided by the High Dam Reservoir. This was sufficient to supply the requirements of Egypt and the Sudan, amounting to about 70 mld cu. m annually for about 2 years should the Nile cease to flow altogether during that period. The scheme thus disregarded cost entirely, and in a country where the whole capital outlay had to be found by domestic and foreign loans.

- (d) It would appear that when the capacity of 130 mld cu. m had been discovered by air survey, Hurst and Black decided to make full use of it. This was evident from the arbitrary choice of 30 mld cu. m for annual regulation and flood relief and 30 mld cu. m to a silt-trap, over and above an over-year capacity of 70 mld cu. m without giving any explanation how their choice had been made, as pointed out in § 70.
- (e) In order to get the High Dam scheme under way promptly, Egypt, which had to bear its entire cost, had signed the Nile Waters agreement which gave the Sudan 14.5 mld cu. m of the benefit accruing from that scheme and Egypt 7.5 mld cu. m only. Egypt in addition would pay the Sudan an indemnity of £15 million for the rehabilitation of the people whose land would be submerged by the High Dam.

518. Much more could be said about the methods used for the estimation of evaporation losses and about ignoring seepage without making any geological or hydrological investigation of the site whatsoever—all of which must seem strange to an engineer.

519. Mr Labib had begun by explaining how Hurst had arrived at an over-year capacity of 70 mld to ensure a draught of 72 mld cu. m. Some of his expressions were not precise. For example, he had written of evaporation and seepage losses amounting to 10 mld cu. m when he had meant evaporation only. The following statement (§ 421) was another example:—

“In applying Hurst’s statistical equation losses had been ignored. By allowing for these losses in the High Dam it was evident that a greater draught could be obtained.”

If he meant that the net draught had been increased by the losses in the High Dam, it showed that, like Mr Simaika, he had overlooked the arguments of §§ 57 and 58, which were amplified in the Author’s reply to the latter, § 503.

520. There were other similar clauses which were typical of those published in the local press from time to time by the Sadd-el-Aali Authority of which the following might be quoted:—

- (a) The optimum capacity of 130 mld cu. m would safely serve the different purposes for which the High Dam was constructed including irrigation, power production, flood protection, navigation, fish culture, and other multiple purposes (§ 427).
- (b) The optimum height of the dam had been checked by cost-benefit analysis and it was found that the expected increase of national income would cover the cost of the whole project in less than 2 years (§ 428).

521. He had given the results of a trial regulation which he had carried out for the years 1879–1953, after deducting the losses corresponding to the successive accumulated storage from each annual flow, and had obtained a standard deviation of 15.6 instead of 19.8 obtained by Hurst and Black for the unaffected flow for the same period, as given in the official report¹¹. And, using Hurst’s equation (3) (§ 51), he had found that with an over-year capacity of 70 mld cu. m the net draught came out as 74 mld cu. m which compared favourably with 72 mld cu. m obtained by Hurst and Black for the same over-year capacity. He therefore concluded that the trial regulation he had carried out with the affected flow for each year confirmed the results obtained by Hurst and Black for the unaffected flow and eventually reduced by the losses (§ 422). This was

probably the most subtle fallacy in the whole discussion, and at least one or two more contributors besides Mr Labib had been misled by it.

522. It should be pointed out at the outset that no parallel could be drawn between the case worked out by Hurst and Black in the official report and the trial regulation carried out by Labib, because they represented two entirely different conditions. In the former case the annual losses were taken as constant, namely, 10 mld cu. m, while in the latter case the losses varied each year with the accumulated storage, throughout the whole period of regulation, so that the losses to be deducted from each annual flow were not constant but varied from year to year. Hence the difference between the natural and the affected flow was a variable quantity and consequently the standard deviation and mean draught were different from those obtained by Hurst and Black in the former case. With such widely divergent conditions it was difficult to see why they should yield approximately the same result, and this must therefore be taken as a mere coincidence.

523. The same conclusion might be stated in another way. The case considered by Hurst and Black referred to normal running conditions when the reservoir would be operating between R.L.182 and R.L.175 with approximately constant losses varying between about 10 and 8 mld cu. m. The case considered by Labib on the other hand, referred to the initial filling of the reservoir which was a transient condition before it had reached its normal state of operation. Consequently, no definite conclusions could be drawn from a comparison of results obtained under such entirely different conditions.

524. The same remarks would apply to the trial regulation carried out by Mr Labib for the period 1899–1953 (§ 423).

525. Mr Hawes had also followed the same procedure of trial regulation and had obtained a capacity of 100 mld cu. m; this included 70 mld for over-year storage and 30 mld for annual regulation and flood relief, but excluded the silt-trap, which he said had agreed with the results obtained by Dr Hurst (§§ 306–308). As explained above, the conditions were not the same in these two cases and the above observations applied equally well.

526. As shown in § 59, the rigorous method of calculating the over-year capacity from past records of Nile discharge was that of continued sums of departure, and of adding a separate capacity for housing the losses while they were being dissipated in the reservoir in the manner explained in § 58.

527. Mr Allan had done the same thing in deducting the losses corresponding to the accumulated storage from the flow of each year, and by using the digital computer had arrived at results which he had stated had confirmed the results obtained by Hurst and Black, but which, on close analysis, had proved to be quite different.

528. Mr Allan had dealt with reservoir capacity of the High Dam and the general problem of Nile control, as well as the Wadi Rayan project. Only the first two would be dealt with under the present head.

529. On the capacity question he had quoted in § 400 the figure of 117 mld cu. m, as obtained by Morrice and Allan³⁹ using the digital computer for the range of effective capacity needed at Aswan, which he stated in § 401 was not far short of that obtained by Hurst and Black.

530. It should be noted, however, that in their calculation, Morrice and Allan had allowed for a dead storage of 30 mld cu. m and Mr Allan had mentioned that about one-quarter or about 29 mld cu. m had been allocated to annual storage. This would leave 88 mld cu. m for over-year storage against the 70 mld cu. m of Hurst and Black.

531. Again, in their calculation³⁹, Morrice and Allan had included for an additional discharge of 9.65 mld cu. m as the estimated benefit from the Upper Nile project over and above a mean Nile discharge of 83.77 mld cu. m, making a total of 93.4 mld cu. m. Deducting the losses of 8 mld cu. m as they had estimated, would give a net discharge of 85.4 mld cu. m for which they had provided an over-year capacity of 88 mld cu. m. On the other hand Hurst and Black had taken an over-year capacity of 70 mld to ensure a net draught of 72 mld.

532. Bearing in mind that a reduction of draught made a larger proportional

reduction in the capacity, it followed that if the draught taken by Morrice and Allan was reduced from 85.4 to 72 mld cu. m, which was the figure taken by Hurst and Black, then according to Hurst's formula the capacity obtained by Morrice and Allan would be reduced from 88 to about 20 mld, which agreed with the result obtained by the Author in § 58 for a draught of 72 after applying the correction he had introduced for taking account of losses.

533. Thus, contrary to what Mr Allan had asserted in § 401, the results obtained by the digital computer tended to confirm the Author's results and method of working, rather than those of Hurst and Black. The Author, however, did not dogmatize. He was inclined to consider that the agreement was a coincidence rather than a proof of the validity of his results. For, as previously shown, the regulation test carried out by Morrice and Allan, like that of Labib, referred to initial conditions, while the results obtained by the Author from those given by Hurst and Black referred to normal running conditions, although the two cases could well yield results of the same order of magnitude.

534. The Author was in full agreement with Mr Allan's statement in § 397 that the optimum expansion of irrigation in the Nile Valley required regulation of the whole of the available flow, while at the same time keeping the losses as low as possible, so that ultimately all the flows whether silt-laden or not must be controlled and used.

535. He differed from him, however, on the method to be used for achieving that object. Hurst and his colleague had provided a large reservoir of 130 mld and Morrice and Allan had taken a somewhat smaller one of 117 mld for combined over-year and annual storage.

536. The Author, on the other hand, had planned to separate over-year from annual storage, and to provide an independent reservoir capacity for each storage. As shown in the Paper, by choosing off-stream sites for the over-year reservoirs, such as at Wadi Rayan, only the silt content of the water actually stored in these reservoirs would be deposited therein, while the river would continue to carry silt-laden water to the land as usual. In this manner such an off-line reservoir would not appreciably affect the silt regime of the river. The land would thus continue to be irrigated by silt-laden water during the flood season, which amounted to half the annual water supply normally reaching the land.

537. On the other hand, by combining over-year and annual storage in the same reservoir, as in the High Dam scheme, all the silt would be deposited therein, and the land would be irrigated by silt-free water all the year round.

538. This had constituted the main difference between separate and combined storage. Thus, while both systems would achieve full control and full use of the whole of the Nile water, whether silt-laden or not, separate storage had the advantage of maintaining the silt regime of the river as it stood at present.

539. The following sites had been selected for over-year storage:—

1st stage: Wadi Rayan, 12 mld cu. m.

2nd stage: Lake Tana, 15 mld cu. m. (Morrice and Allan estimate.)

To these might be added, should experience prove it to be necessary, the Baro (Sobat) Reservoir with a capacity of 5.5 mld cu. m (to quote again the estimate of Morrice and Allan) making a total of 32.5 mld cu. m, which would be more than sufficient to cater for the lowest year 1913–14, or the equally unfavourable succession of low years 1925–27 or 1940–45, mentioned by Mr Allan in § 398.

540. For annual storage any combination of the following reservoirs might be chosen:—

Aswan	5 mld cu. m
Semna Gorge	25* "
Merowe	10 "
Roseires	6.5* "
Kashm-el-Girba	1.1* "
	<hr/>
	47.6 "

* Estimated by Morrice and Allan³⁹.

541. On the complete solution of the problem of Nile control, Mr Allan was less dogmatic and indeed more realistic than when he was advocating the large capacity of the High Dam Reservoir. He believed that on present knowledge the safest method was to ascertain what could have happened if past discharges were repeated, assuming certain reservoirs were available and allowing for the inevitable losses. When by repeated trial and error a solution had been found for the total storage necessary to maintain a given draught a reasonable margin of safety could be added (§ 399).

542. This was a sound line of approach towards the final solution of Nile control, in which the Author fully concurred. In fact it had identified their views on the question of Nile control and its comprehensive solution, which did not seem possible when Mr Allan discussed the High Dam and its reservoir capacity.

543. Indeed, the above statement implied that the High Dam was by no means a final solution for full Nile control as asserted in the official report¹¹. There, it had been emphasized that there was no alternative to the Sadd-el-Aali proposal to provide the maximum volume of Nile water for the development of Egypt and the Sudan. It implied further that the final solution was still to be sought by repeated trial and error, as Mr Allan had stated.

544. He was quite right when he mentioned in § 400 that that would involve an immense amount of work and that he knew no better method than that adopted by Morrice and Allan using the digital computer. It must be pointed out, however, that although it was the most powerful tool available for computation purposes, it was after all only a labour-saving device, and the validity of the results it yielded depended entirely on the validity of the assumptions made in the preparation of the data fed into it.

545. With only a few annual reservoirs and not a single over-year reservoir yet on the Nile, or any other river in the world for that matter, the available data on regulation and losses were very scanty and entirely inadequate for forecasting a comprehensive scheme of Nile control with all the required over-year and annual storage, so that one had to resort to various assumptions which would be mostly speculative and totally unsuitable for forecasting a complete and reliable solution of the storage problem.

546. For instance, in the elaborate and valuable study made by Morrice and Allan, only the evaporation losses were taken into account, albeit, by means of readings which were taken by primitive methods many years ago, and without any up-to-date confirmatory experimental evidence. At the same time seepage was ignored altogether; the fact that it could not be readily measured was no reason why it should be ignored.

547. Under the circumstances no reliability could be placed on the results obtained by the computer, accurate as it might be in the performance of its function. It was thus now evident that it would be futile to attempt the formulation of a complete solution of the storage problem which would include optimum annual and over-year storage, mainly because of inadequate factual data.

548. It was all very well to play for safety, by taking the largest reservoir capacity found by air survey. If it proved too large in future, one had the excuse of having played safe. This would be a wrong attitude to take and certainly incompatible with engineering principles.

549. The valuable researches of Hurst and his colleague, probing into the future by probability conjectures, if incomplete, and those of Fathy and Shukry, as well as the methodical and painstaking work carried out by Morrice and Allan had cleared the way for all but a complete solution of the storage problem, and had fully confirmed the Author's misgivings about the futility of the High Dam scheme as the final solution, that its supporters had claimed it to be. These results had indeed demonstrated that the complete solution was still far from being realizable in the near future.

550. In the Author's opinion the right course would be to formulate a general policy of Nile control and to lay down certain guiding rules such as had been outlined in the Paper, and in particular the principle of separating annual and over-year storage and placing the latter at off-stream sites wherever possible in order to overcome the silt difficulties. Within the framework of such a general policy one or two reservoirs might

be selected for immediate execution, say, one annual and one over-year, as proving to be technically and economically feasible, in order to meet the hard-pressed need for the expansion of cultivation. Wadi Rayan and Semna Gorge appeared to be the most suitable for that purpose. When they had been in operation for some years the data collected therefrom regarding regulation and losses could be utilized for forecasting the next set of reservoirs by trial and error, until the entire chain of Nile control projects was completed. This line of procedure might be followed in carrying out the plan proposed in the Paper with respect to annual and over-year reservoirs and extended to cover the provisions of § 179 *et seq.*

551. There was no desperate hurry for providing such a large storage of 130 mld cu. m when Egypt and the Sudan had been going on for all the past years with no provision for over-year storage whatsoever, and without much inconvenience. The provision of 12 mld cu. m available from Wadi Rayan at a comparatively small cost and with insignificant losses, could be a timely and welcome safeguard against low years with the exception of years like 1913–14. In the Author's opinion, that year would probably never be repeated, for reasons which he would explain later (§ 634). There was room for much legitimate difference of opinion as to what should be the ultimate storage capacity required for complete Nile control, as envisaged in § 179 *et seq.*, and where and how it should be distributed in the Nile Basin, yet few, in the Author's opinion, could disagree on the necessity for the immediate provision of one or two reservoirs of reasonable size to meet the requirements of the present and the immediate future of Egypt and the Sudan.

552. On the question of how to determine the over-year capacity of reservoirs in general, raised by Mr Sharman in § 336, the Author was generally in favour of using the method of continued sums of departure. It was rigorous, straightforward, and independent of storage losses. He had used it for the determination of the capacity required to ensure a steady draught of 72 mld for the period 1899–1953 which had given a capacity of 30 mld.

553. As pointed out in § 59, that capacity happened to be equal to the deficit in the lowest year 1913–14. The reason was pretty obvious. That year was abnormally low, being 42 mld cu. m, which was 50% lower than the next lowest year 1899–1900 with a discharge of 63 mld cu. m. With a different series of discharges such a coincidence would be unlikely to happen. Thus, the Author did not simply take the capacity as the maximum deficit of the lowest year, as Mr Sharman had thought and described as disarmingly simple (§§ 334 and 335).

554. The line of approach which the Author would be inclined to follow for the determination of the over-year capacity to ensure a given draught was to use the method of continued sums of departure for the past records, and to check by Fathy and Shukry's method for possible recurrence of past records in the most unfavourable order, and eventually to use Hurst's formula for future forecasts, using in all cases the Author's method of taking losses into account as shown in § 58.

555. It should be emphasized, however, that none of the above methods should be considered conclusive as regards the size of the reservoir, but merely as a guide for the designer. The final choice must depend on a study of local and economic conditions, particularly on a careful balance between capital outlay and yield. He would be inclined to choose a capacity which was on the low side to start with but always with adequate provision for future increase should this prove desirable. The ultimate size could only be determined by trial and error. To err on the high side might unduly raise the cost, while no harm would be done if too small a capacity were chosen. It could always be raised. The choice, however, even in the preliminary stages would require insight, sound judgement, and considerable experience which were of more importance than any statistical empirical formulae.

Reservoir losses

556. With regard to reservoir losses, Dr Hurst had said in § 286 that losses and gains described in the Paper were the difference between discharges at Wadi Halfa and Aswan,

and therefore depended on the accuracy of the discharge readings. He had devoted much space to prove that discharge readings were unreliable at Aswan before 1902 and at Wadi Halfa before 1921. This question had been already discussed in §§ 200–202 and §§ 214–217.

557. The whole of his argument, however, was based on the postulate that losses or gains depended entirely on discharge readings, ignoring the established fact that the Nile had actually crossed a water-bearing bed whose water-table was R.L. 100 m (Fig. 13), which was always higher than the river water level even in flood time. This would invalidate that postulate entirely. Nor could he have read the Paper closely where it was shown in §§ 213, 216, and 217 that one was not dealing with an ordinary reservoir with normal storage losses only, but with one where exchange between river and ground-water was decisive in matters of gain or loss; it might raise or lower the losses, nullify them, or change them into gain.

558. Another factor amply demonstrated in the Paper was the influence of silting which formed an isolating layer separating river- from ground-water which could be wholly or partially removed by scouring during flood, thus exposing more permeable beds and therefore promoting exchange of river- and ground-water, as shown in § 234. Although no conclusive results could be drawn from the discharge readings before 1921, some qualitative information might no doubt be reasonably inferred from the general trend of the analysis results shown in Fig. 10.

559. With the water-table standing at R.L. 100 m, the prevalence of gain before the building of Aswan Dam, the alternation between gain and loss after its building to a storage level of R.L. 106 m, the prevalence of loss after it was heightened to a storage level of 113 m, were all clear manifestations of the influence of ground-water which would readily account for those large gains and losses if a broad and realistic view was taken of the situation and if one recognized the presence of ground-water and did not put all the blame on Halfa discharge readings.

560. Dr Hurst, referring to the years 1916–18 (Fig. 10), had said that 1916 and 1917 were years of high flood. The first had produced a supposed gain of 4 mld cu. m and the second neither gain nor loss, while 1918, a low flood of short duration, had produced a loss of 8 mld cu. m, which he had described as absurd.

561. In § 287 he had referred to the years 1890–1902 (Fig. 10) as showing large gains, although they were years of high flood. He had analysed the losses month by month in Fig. 15, pointing out that while the river was falling there were no gains but only losses. As soon as the river began to rise the gain began, and continued up to and during the peak of the flood which was the inverse of what would happen on the accepted theory of the movement of underground water, and the results could not be explained on any rational hydrodynamical theory.

562. In fact, they could all be explained on one of the simplest of all laws of nature, if instead of speaking of the movement of river water one spoke of interchange of ground- and river-water, and the resultant pressure was taken as the motive force which determined the direction of flow one way or the other, instead of merely river-water level which Dr Hurst evidently had in mind. Opposing the flow were those isolating layers of silt deposits which were liable to break down any moment by scouring or by ground-water upthrust, thus assuming any resistance between zero and infinity.

563. With the water-table always higher than the river there would generally be more or less gain in flood time depending on the intensity of the flood and the extent of scouring. Thus, the years 1890–1902, before the building of the Aswan Dam, being of high flood the scouring of the bed was great, which enabled the ground-water to get the upper hand. There was more gain when the river was rising in flood time because scouring was greatest and probably none when the river was falling, which would explain Fig. 15.

564. The case of 1916–18, when Aswan Dam was in operation, was not so simple, being complicated by the storage losses. There was generally a gain during the flood period, and storage losses during the rest of the year by seepage and evaporation. In

1916, which was a year of high flood, there was a large gain which outweighed storage losses. In 1917, when there were no gains or losses, the gain during the flood must have balanced the storage losses. In 1918, with low flood and short duration, the gain was probably small compared with the storage losses, resulting in an overall loss.

565. Dr Hurst and the Author were, however, in agreement that the losses analysed after 1921 might be taken as reasonably correct. This would now be discussed.

566. Dr Hurst had analysed the losses of Aswan Reservoir in the interval 1921-52, and had found the mean annual loss for 24 years to be 0.5 mld cu. m. The results of his calculations were given in Table 23. It was shown in that Table that that interval was divided into two separate periods, 1921-33, when the reservoir capacity was 2.5 mld cu. m, and 1934-52 when it was 5 mld cu. m. Although the losses were calculated for each period separately they were added up together and the mean of the whole interval was calculated and was taken as 0.5 mld cu. m as mentioned above.

567. The Author had pointed out that that figure was misleading since the losses were bound to be greater during the first period than during the second. This was evident from Table 23, where the mean annual loss worked out as 0.63 mld cu. m for the first period and 0.39 mld cu. m for the second period. Hence, the above mean of 0.5 mld cu. m for the two periods had actually concealed more than it had revealed.

568. It should be noted that the storage level in Aswan Reservoir was 8 m higher and the evaporation surface much larger during the second than during the first period, yet the losses during the first period were nearly double those of the second period. The obvious explanation, and the only possible one, was that seepage was greater during the first period than during the second. Hence, adding up the two periods together and finding the mean loss of the whole interval of about 30 years had concealed a remarkable and important fact brought out by Table 23, namely, that seepage was much greater during the first than during the second period, and consequently the mean of 0.5 mld cu. m for the two periods was of no significance and indeed misleading as mentioned above. Yet Dr Hurst had used it to prove that there was no seepage in Aswan Reservoir, since the evaporation losses which he had previously calculated were of about the same order of magnitude. Naturally, seepage was bound to be greater in the period before 1920, even if it could not be measured accurately because Halfa discharges were uncertain.

569. Comparing the above results with his own the Author had observed that the mean loss during the first period had agreed with his own figure given in § 219, but it differed in the second period for the reasons given in §§ 224 and 225. At all events the results of the calculations made independently by Dr Hurst and the Author had both agreed that the mean loss during the first period 1921-33 was 0.63 mld cu. m, which represented 25% of the reservoir capacity of 2.5 mld cu. m, and by analogy would represent the probable annual loss in the High Dam scheme in the corresponding period. This would represent a loss of 32.5 mld cu. m in the High Dam which would reduce the volume of water available for Egypt and the Sudan below its present amount. Notwithstanding this unequivocal evidence brought out by his own calculation in Table 23, Dr Hurst had concluded his contribution by saying that all evidence showed that seepage was likely to be negligible in the High Dam scheme (§§ 288, 239).

570. Mr Black had said in § 386 that gains or losses on which the Author had based his remarkable theory of the dire effects of the High Dam existed only in his imagination. Mr Black was wrong at least in one instance where those losses had existed in reality and he knew it. For he and Dr Hurst had made together the analysis in Table 23, where the losses during the first period amounted to 25% of the reservoir capacity. In their joint report, however, they only gave the mean loss for the two periods together, which was misleading. Table 24, pp. 391-395, gave an analysis of losses in the Aswan Reservoir, summarized in Table 23, p. 379.

571. Dr Hurst's views on the movement of ground-water were no more sound, nor his approach any more practical, than his assessment of seepage losses in Aswan and the High Dam reservoirs. He evidently believed that the velocity with which ground-water moved to the Libyan Desert, for instance, could be determined from a laboratory test

carried out on a sample of sandstone (without fissures) as specified in that test. He had included in his contribution Table 16 which gave the velocity of percolation in various samples of sandstone taken from different countries and pointed out that Nubian sandstone appeared to be more permeable than other specimens.

572. He had stated (§ 289) that the Author had given in the Paper some of the known data about the movement of groundwater in the Libyan Desert but had left out the most important of them all, namely, the slow rate at which it percolated through sandstone which was found by Hellstrom²³ to be 15 m a year, from which he had calculated that it would take the water 100,000 years to travel from the intake beds to the Qattara depression near the Mediterranean Sea.

573. The Author pointed out that in practice ground-water movement always followed lines of least resistance, such as faults, fissures, and lines of cleavage in general. Investigation of seepage in any particular site involved geological and hydrological surveys of underground structures with reference to rock formation as well as tracing and mapping out such water passages as could be detected nowadays with fair accuracy by geophysical means. It was never based merely on laboratory tests as implied by Dr Hurst's statements. Neither was the movement of ground-water ever based on the assumption that rock was as homogeneous and compact as specified in the laboratory tests, so that the conclusion that water would take 100,000 years to make its journey to the Mediterranean Sea was invalid and entirely unrealistic.

574. Mr Sharman had mentioned in § 337 that in the course of investigating the hydrology of some small river basin in British Guiana, it had been found possible by daily readings on a network of observation wells to determine the magnitude and direction of contribution of that source to the river flow whether positive or negative. He had expressed surprise that no such investigation had been made at the site in respect of Aswan and the High Dam Reservoirs, and asked if the terms of reference of those who had designed and redesigned the High Dam had included the task of assessing the probable seepage losses.

575. The Author knew that no such investigation had ever been made, apart from borings made in the sites of the High Dam itself (§ 97), which, if anything, had shown that seepage in the site was likely to be large. Nor had the terms of reference of the International Commission included any such investigation.

576. Dr Hurst had stated in § 291 that the water now reaching the Nile and the Great Oases fell in the geological lines which Murray had aptly called "fossil" water.

577. The Author had observed that there was evidence of such water which had been stored from the geological ages and had made its appearance for the first time on the earth's surface. It was generally known as "plutonic" water, and the Author had come across a few such cases in the course of his study of the underground water resources of Tripolitania, but never on such a large scale as had fed the Nile and the Great Oases from time immemorial.

578. A well-known feature of "plutonic" or "cistern" water, as it was sometimes called, was the depletion of wells fed from it with the lapse of years. This was the reverse of what was happening at the Great Oases, which showed that the increase was probably due to seepage from Aswan Reservoir.

579. Mr Murray had made the same mistake and estimated in § 392 that it would take the water 91,500 years to travel from Central Africa to Egypt, assuming that it travelled through compact sandstone with a velocity of 15 m a year.

580. He had stated (§ 391) that the Author had quoted in § 230 a percolation rate of 150 m a day as given by Ferrar²⁵ which he had personally known to be due to special local conditions where the subsoil was mostly coarse sand, and said that the Author had ignored the velocity given by Hellstrom²³.

581. To this observation the Author replied that he had merely done what any engineer in his place would have done, namely, to recognize the results of a field test taken under natural conditions, preferring this to a laboratory test made under certain specified conditions, with the usual precautionary measures of eliminating as far as

TABLE 24.—ANALYSIS OF LOSSES IN ASWAN RESERVOIR, 1921-22 TO 1950-51
(summarized in Table 23, p. 379)
Discharges are given in million cubic metres

	1921-22		1922-23		1923-24		1924-25		1926-27	
	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan
November . . .	7,100	7,100	8,100	8,200	—	3,900	—	—	7,500	8,000
December . . .	4,600	3,200	5,100	3,400	4,800	—	5,300	4,500	4,800	3,500
January . . .	3,400	3,000	3,600	2,700	3,700	3,000	3,800	2,500	3,800	2,800
February . . .	2,000	2,000	2,000	2,200	2,400	2,400	2,500	2,400	2,700	2,800
March . . .	1,400	1,500	1,300	1,600	1,600	1,900	1,800	1,900	2,000	2,000
April . . .	1,000	1,400	1,100	1,500	1,200	1,800	1,400	1,700	1,600	1,800
May . . .	900	1,500	1,500	2,100	1,400	2,100	1,300	2,100	1,600	2,200
June . . .	1,000	1,800	2,400	3,300	1,600	2,500	1,600	2,600	1,500	2,600
July . . .	3,800	3,700	5,100	4,400	5,700	5,600	4,400	4,100	4,800	4,500
	25,200	25,200	30,200	29,400	22,400	23,200	22,100	21,800	30,300	30,200
Loss . . .	0		800		— 800		— 700		100	

TABLE 24.—*continued.*

	1927-28		1928-29		1929-30		1930-31		1931-32	
	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan	Halfa	Aswan
November . . .	5,500	4,400	6,600	6,400	—	—	5,200	3,500	8,700	7,300
December . . .	3,700	2,900	4,400	3,400	5,200	3,500	3,700	3,200	5,700	4,300
January . . .	2,600	2,200	3,500	2,800	4,200	3,300	2,700	2,400	4,200	3,500
February . . .	1,700	1,800	2,200	2,200	2,900	2,700	1,600	1,800	2,700	2,700
March . . .	1,500	1,600	1,800	2,000	2,200	2,100	1,500	1,900	2,000	2,400
April . . .	1,300	1,700	1,500	1,900	1,700	2,000	1,300	1,700	1,700	2,000
May . . .	1,700	2,400	1,800	2,400	1,700	2,500	1,300	1,800	1,700	2,600
June . . .	2,700	3,000	3,800	3,700	1,900	2,800	1,200	2,000	1,800	3,200
July . . .	7,500	6,600	10,000	9,400	5,600	4,700	3,400	3,100	7,600	6,500
	28,200	26,600	35,600	34,200	25,400	23,600	21,900	21,400	36,100	34,500
Loss . . .	1,600		1,400		1,800		500		1,600	

TABLE 24.—*continued.*

	1934-35		1935-36		1936-37		1937-38		1938-39	
	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan
October	16,500	15,400	—	—	15,600	14,300	13,500	12,400	—	—
November	7,400	6,040	7,520	5,000	6,900	4,500	5,800	3,200	8,800	6,400
December	5,020	3,380	4,950	3,580	4,200	3,590	4,300	3,600	5,300	3,600
January	4,200	3,510	3,950	3,420	3,200	3,000	3,400	3,200	4,100	3,400
February	2,850	2,730	2,640	2,680	1,900	2,200	2,100	2,300	3,200	3,000
March	2,140	2,190	2,230	2,400	1,600	2,300	2,200	2,300	2,300	2,500
April	1,700	2,190	1,770	2,190	1,400	2,000	1,700	2,000	2,100	2,200
May	1,840	3,040	1,730	3,100	1,400	2,400	1,500	2,800	2,200	3,300
June	2,680	4,190	1,800	3,650	1,800	3,200	1,600	3,400	2,200	4,100
July	8,000	7,870	6,230	6,000	4,800	4,700	4,500	4,600	4,200	5,100
	52,330	50,760	32,820	32,020	42,800	42,100	40,600	39,800	34,600	33,600
Loss	1,500		800		700		800		1,000	

TABLE 24.—*continued*

	1929-40		1940-41		1941-42		1942-43		1945-46	
	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan
October . . .	12,400	10,500	7,800	9,800	11,000	8,600	14,500	13,900	15,900	14,800
November . . .	7,600	5,300	2,900	4,300	7,400	5,400	5,500	3,300	8,000	4,800
December . . .	4,400	4,200	2,400	3,000	4,000	4,100	3,800	3,000	4,900	4,700
January . . .	3,200	3,200	2,200	2,000	3,000	2,700	3,000	2,500	3,700	3,700
February . . .	3,200	2,400	2,100	1,800	2,100	2,400	1,800	2,500	2,300	2,800
March . . .	2,500	2,300	2,100	2,200	2,500	2,400	2,500	2,200	2,500	2,300
April . . .	1,800	2,100	2,000	1,700	2,500	2,500	2,200	2,400	2,500	2,300
May . . .	1,400	3,000	2,600	1,200	1,800	3,300	1,600	3,100	2,100	3,000
June . . .	1,600	3,400	3,600	1,900	1,900	4,000	1,600	3,400	1,600	4,200
July . . .	3,400	4,000	4,700	4,400	5,400	5,600	3,300	4,000	7,400	7,200
	40,400	40,400	32,400	32,300	41,700	41,000	39,800	40,300	50,900	49,800
Loss . . .	0		-100		700		-500		1,100	

TABLE 24.—*continued.*

	1947-48		1948-49		1949-50		1950-51	
	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan	Kajna	Aswan
October	13,900	12,100	15,500	13,700	13,200	12,200	14,100	12,900
November	5,800	4,100	8,700	8,100	7,000	4,800	5,900	3,300
December	4,100	4,200	4,600	3,900	4,400	4,200	3,800	3,900
January	3,400	3,400	3,500	2,500	3,800	3,100	3,100	2,800
February	2,700	3,000	2,600	3,100	2,700	3,000	1,900	2,900
March	2,500	2,500	2,400	2,400	2,500	2,500	2,300	2,400
April	2,600	2,400	2,500	2,500	2,500	2,500	2,400	2,400
May	2,200	3,200	2,600	3,200	2,700	3,400	2,000	2,900
June	1,800	4,500	2,000	4,500	2,300	4,600	1,300	3,700
July	5,900	5,600	4,600	5,500	5,400	5,400	3,400	3,800
	44,900	45,000	49,000	49,400	46,500	45,700	40,200	41,000
Loss	-100		-400		800		-800	

Note: (a) Aswan discharges are those given in "The Nile Basin", vol. 7, by H. E. Hurst, R. P. Black, and Y. M. Simaika.

(b) Wadi Halfa discharges are the corrected values given in "The Nile Basin", vol. 4, Suppl. 2, by H. E. Hurst and P. Phillips.

(c) When the second heightening of Aswan Dam was completed to R.L.122 in 1933, Halfa came within the reservoir, and a new discharge station was therefore installed at Kajna, about 47 km upstream of Wadi Halfa.

possible all indeterminate factors. Such tests were generally made for guidance and were never meant to be literally applied in actual practice.

582. Mr Murray's argument in § 392, however, that fluctuations in the rainfall at the intake beds were likely to be ironed out by long distance of travel appeared to be sound.

583. He had mentioned in § 393 that the increase of discharge in the oases was due to the fact that many more wells had been sunk at Dakhla Oasis during the 20th century which had now depleted by 5 m or more. The first part of his argument was inconclusive; the increased discharge as a result of the sinking of more wells would not invalidate the Author's postulate that the water had come from Aswan district any more than it would support the assumption that it came from increased rainfall in Central Africa.

584. The recent depletion, however, was consistent with the fact that seepage from Aswan Reservoir had diminished in late years after the reservoir basin had sealed up, rather than from any assumed decrease in rainfall at the fountain head, unless Mr Murray believed that the source of supply was "fossil" water. Dr Hurst seemed to give that impression in his contribution, although Mr Murray himself did not say so in his own contribution.

585. It was difficult to see how Mr Murray had concluded in § 394 from Fig. 13 that the artesian water contours did not bulge out away from the river as they should do from an intake area. For, there were only two contour lines shown in that map in Upper Egypt and both crossed the river, the first at Dekka and the second at Beni Suef, indicating that the river water was actually in contact with ground-water at those points. The direction of flow depended on the river water level in relation to the water-table, which determined whether there was a gain to or loss from the river.

586. It was fair to assume that after the erection of Aswan Dam, water had probably percolated into the southern part of Upper Egypt. From Beni Suef northwards, however, most of the artesian water was trapped in the surrounding chain of depressions causing the contour line or water-table to fall to zero and was therefore 20 to 30 m lower than the river water level in that region. Consequently the chances were that any water percolating into the river in the southern part of Upper Egypt would percolate out again to feed the ground-water in the northern part, so that no conclusions either way could be inferred from the scanty contour lines shown in Fig. 13. The only definite conclusion was that river-water was in contact with ground-water.

587. In § 311 Mr Addison had made a similar analysis of artesian water contours shown in Fig. 13, to which most of the above observations would apply. It would appear, however, that the Nile flowed in a trough of clay and silt of Nile formation which was practically isolated from the surrounding sandstone aquifer by means of an impermeable layer which had invariably to be pierced wherever it was desired to sink an artesian well into water-bearing beds. With the exception of such wells, all other wells sunk in the Nile Valley showed unmistakable signs of bank charge where the sub-soil was charged in the flood season, and the water returned to the river when it fell; the rise or fall of water level in the wells followed that of the river with a certain time lag.

588. Mr Labib had made a similar observation in § 431 about the increase of the oasis discharges as being due to sinking more wells. He added that an experiment which was carried out this year on the Nubian sandstone proved that its permeability was low. This was contrary to the results obtained by Hellstrom and quoted by Hurst in Table 16.

589. Mr Gruner had observed (§ 480) that the velocity of flow through sandstone, of some metres per year as obtained by Hellstrom in his laboratory tests, was so low that he wondered if the factor of impregnation had not been mistaken for the phenomenon of percolation through the rock.

590. Moreover, seepage always followed lines of cleavages in the various rock formation which accounted for the short time taken by ground-water to travel from one place to another.

591. He had given in § 478-9 interesting illustrations of the interchange of ground- and river-water in Syria and in the Rhine Valley. He had also mentioned that in the case of the Montejacque Reservoir in Spain the seepage loss was so heavy that the reservoir had failed.

592. Mr Sharman had given an impressive description of his experience of the abundant yield of water produced when a tunnel was driven through a water-bearing bed of sandstone under medium head even when the permeability measured on samples was low (§ 338). He had observed that with the very flat ground-water gradient implied by Fig. 13 the net average movement of ground-water would be extremely slow. He had added that it was necessary to distinguish between the slow creep of water through an aquifer in conditions of virtual equilibrium, and the more rapid transmission of applied piezometric pressure changes through interstitial water.

593. The Author would like to add to this sound argument that it was true that the outburst of flow had been induced by the cavity created by driving the tunnel through the rock which had disturbed its state of equilibrium, but it was equally true that if the rock had been as compact and free from fissures as the sample tested, that abundant flow could not have persisted for any length of time.

594. Mr MacDonald had referred in § 300 to a dam in Pakistan built by the Irrigation Department in 1958 which yielded about half the quantity of water which had been expected, and he had concluded that that was obviously due to heavy seepage losses.

595. Mr Hawes had mentioned in § 309 a similar experience in Chile, where half the expected discharge with a hydro-electric station had by-passed the station and percolated into the river-bed downstream.

596. Mr Forbes had referred in § 356 to an interesting experiment carried out by the Colorado State Engineering Bureau which found that in a distance of 400 miles there was a gain of 575 cusecs over that at the upstream measuring station with no tributary flow between. He had rightly pointed out that the water returned by seepage in that and in similar cases depended on local conditions of the underlying strata.

597. Mr Allan had discussed the question of seepage in the High Dam scheme from a different angle. He did not concur with the Author's forecasts of seepage losses in the High Dam Reservoir when filled (§ 403) and believed that the dead storage of 30 mld cu. m would extend to the Second Cataract above Wadi Halfa, a distance of more than 350 km from Aswan; in that length of almost entirely still water silt would be deposited, mostly, it was true near the upper end of the reservoir. This would tend to diminish the rate of seepage as time went by.

598. In the Author's opinion, however, beyond the uppermost reaches of the reservoir practically no silt would be deposited in that distance of 350 km to Wadi Halfa at all. Since the carrying capacity of water for silt varied as the sixth power of its velocity, practically all the silt load would be deposited as soon as the water entered the reservoir. Silt would continue to be deposited until the section had been so much diminished as to enable the river velocity to rise sufficiently to carry the silt load to the next reach in the reservoir. Scores of years might be needed before any appreciable silt deposit would reach Wadi Halfa and still longer, if ever, the middle or the lower reaches, where the water level was highest and seepage presumably greatest. Meanwhile, seepage water would continue to charge the surrounding rock formation.

599. To put it in another way, the entire dead storage would spread slowly and gradually, beginning at the entrance to the reservoir to such a depth and such a distance as would slowly raise the water velocity to its limiting carrying capacity. It was easy to show with a simple piece of calculation that this process of silt deposit would not extend far beyond the uppermost reaches after the lapse of, say, 50 or 100 years of the estimated life of the dam of 300 years. In the meantime seepage would continue from the High Dam Reservoir at even greater rates than it did from Aswan Reservoir, where silt deposit was more or less uniform in the flood season. Even at Aswan, as shown previously, seepage had continued 30 years after the building of the dam.

600. This theory was supported or rather initiated from an experience which the Author had had. In a lift irrigation scheme in Upper Egypt, which included about

twenty pumping stations, he had envisaged concrete culverts for the pump intakes which had to be deep and extending far enough into the river channel so as to be always under water when the river fell to its lowest level, and tenders were invited on that basis.

601. In the meantime he had inspected culverts of pumping stations on the Nile which had been in operation for many years. He had found that a heap of hard mud had been formed inside the culvert near the entrance, while there was practically no silt deposit in the rest of the culvert. The heap was so high that only a narrow bottleneck was left for the passage of water drawn by the pumps. That was a common feature of the culverts he had inspected, and he had discovered that they had to be cleared of the mud heap every year after flood. He had therefore to change the design of the intakes of these pumping stations and to specify pipelines sloping towards the river³ in place of the concrete culverts. The tenderers were informed accordingly before the offers were sent in.

602. Mr Simaika had asserted (§ 454) that the Author's statement in §§ 207 and 220 that there were isolating layers of silt which separated river-water from ground-water which was washed away during flood time was contrary to evidence. Yet in the same paragraph he had stated that in the flood season the mean water velocity was higher than 1 m/sec and the bed was continually being removed.

603. Commenting on the Author's postulate that since the building of Aswan Dam at the beginning of the century the river had lost a considerable quantity of underground water in addition to storage losses, he had stated in § 454 that there was no doubt that there were high floods in the 19th century due to heavy rainfall which were responsible for the discharge being higher than in the present century.

604. In § 246 it was stated that the losses caused by Aswan Dam, together with a reasonable drop in rainfall accounted for the reduction of discharge in the present century.

605. Referring to Mr Simaika's remark in § 453 about the Author's quotation of Ball (§ 226), the Author pointed out that an error had crept into that quotation. It should read that Ball had observed that the water-table feeding the wells was higher than the water level of the river. This error, however, did not affect Ball's argument or the conclusion he had arrived at, namely, that the river was probably drawing considerable quantities of ground-water. The following was a summary of Ball's argument:—

From various observations of wells on both sides of the Nile he had concluded that the water-table in that locality was 100 m above sea level, while the water level of the river was 99 m above sea level. He had also observed that the water level in one of the wells he had particularly investigated was 98.5 m above sea level and the water was 1.2 m deep. Hence, the water-table was 1 m higher than the water level of the river and 1.5 m higher than that of the well. The fall of the water level in the well was evidently due to the fact that it was being constantly used to supply water for irrigation. It was equally evident that the river could not have maintained the supply of water continuously in the well with only half a metre difference of level over the 750-m distance which separated the well from the river.

The crucial evidence, however, was that the temperature of the water in the well was 83°F, that of the river-water 60°F, and the air temperature 67°F. Moreover, the analysis of the well water was the same as that of the water feeding the Great Oases which was entirely different from Nile water.

606. With regard to evaporation losses, Dr Hurst had said in § 292 that the rate of evaporation was taken by the Piché evaporimeter and the readings were multiplied by a reduction factor of 0.5 which was obtained by comparison with observations taken from tanks floating in the river placed at different places in the country. He had added that it was reasonable to suppose that evaporation from large open surfaces was a little lower than from these tanks.

607. The Author had criticized the instruments and methods used in those tests in §§ 260–267 as being primitive and entirely out-of-date. Besides, such an assumption

that these tanks were near enough to the conditions of large reservoirs was inadmissible, and tanks of 1 sq. m surface area were far too small for accurate measurements.

608. Mr Nimmo had said in § 434 that he shared the Author's views that the magnitude of the High Dam project required more elaborate and precise measurements of evaporation than were at present available. He had given a good description of what had been done in Australia and the United States on the measurement of rates of evaporation. He had shown that experiments had been made with pans up to 12 ft dia. surrounded by water-jackets. In the United States it had been found that a pan of that diameter gave approximately the same evaporation rate as a large water surface.

609. That pan had been used for the measurement of evaporation rates at various places and the results had been given by Mr Nimmo in Table 18. He had concluded that by taking into account atmospheric conditions at Aswan the rate actually used for estimating the evaporation rates for the High Dam, as given in Table 13, were likely to be exceeded. His description was well worth reading since it served as an example of modern methods in contrast to the primitive tests whose results were made use of for estimating the evaporation losses in the High Dam scheme.

610. Mr Lacey had said in § 304 that he was unable to accept the Author's contention that the evaporation losses would be increased owing to the elevation of the water surface of High Dam Reservoir, since the vast sheet of water extending for many kilometres had replaced the Author's plane of reference in the equations which he had employed, and had vitiated the argument that evaporation losses in the High Dam had been under-estimated.

611. The Author said that it had been shown in § 265 that the evaporation rate varied with the wind velocity in accordance with the exponential formula and that the wind velocity varied with altitude in accordance with the log formula³⁴ (Hellman's formula^{57a}).

612. The rate of evaporation at Aswan of 7.4 mm/day, given in Table 13, was used for estimating the evaporation losses in the High Dam Reservoir. Applying the above formulae to that reservoir whose storage level was about 100 m above Aswan, the evaporation rate would be about 40% higher than at Aswan, and would thus be raised from 7.4 to about 10.3 mm/day. The storage level in that reservoir would extend southwards to about the Third Cataract, where the evaporation rate would be about 8 mm/day as obtained by interpolation from Table 13.

613. Mr Lacey had suggested that the sheet of water in the High Dam Reservoir had replaced the plane of reference in those equations, that is, Aswan datum where the rate of evaporation was 7.4 mm/day, ignoring the fact that the rate of evaporation at the water level in the reservoir was 10.3 mm at the northern end and 8 mm/day at the southern end. The Author wished he could be so sure about it as Mr Lacey seemed to be.

614. The question of the variation of the rate of evaporation with the altitude, with respect to a change of datum had not been sufficiently investigated theoretically or experimentally to enable such a statement to be made with any measure of certitude. By raising that point in the Paper the Author particularly wanted to show that estimates of evaporation in the High Dam scheme were based on inadequate premises, and to emphasize the necessity of making special field tests in a project of that magnitude as about altitude of the storage surface.

615. Sir Harold Hartley had referred to a large-scale experiment which had been carried out in Australia in 1948 for the control of evaporation by the use of a monomolecular film of hexadecanol, whereby evaporation had been considerably reduced (§ 475).

616. It had been found that if the film could be maintained on the water surface the evaporation could be reduced by about 30%. For this purpose rafts had been provided carrying containers of the liquid with gauze sides in order to replace the losses caused by wave action.

Silt problems

617. With regard to Nile silt and the problems associated with its deposition and scouring effects, a brief description was given in §§ 15–21 and also §§ 80–81.

618. Sir Harold Hartley had casually referred in § 474 to the deposition of silt in the High Dam Reservoir and the consequent loss of its valuable contribution to the sandy soil. In the Graham Clark Lecture which he had delivered at the Institution in September 1955⁵⁸ he had dealt with silt a little more fully. He said the formation of soil was dependent on the weathering of rocks which in most cases took the form of water-borne alluvium. That was the same material on which, in prehistoric times, the living assemblage which constituted fertile soil developed, with its vast population of micro-organisms, fungi, algae, protozoa, and bacteria, of which there were many millions in a gram of soil. He had mentioned that the forces which smoothed the profile of our planet and produced the soil from rocks were still in action; thousands of millions of tons of rich particles and eroded soil passed down the rivers each year specially in the flood season.

619. In this broad, yet congested, spectrum, Sir Harold had summed up the part played by silt, not only as an essential constituent in the formation of soil in desert land, but also in providing a suitable home for that large assemblage of micro-organic population³.

620. It had been mentioned in § 18 that Nile silt contained fine and coarse sand and about 30% clay. Sand, however, had only physical effects on the soil and was chemically inert. The clay, on the other hand, was chemically active and brought about some remarkable changes in the soil, besides having some important physical effects.

621. The chemical nature of the clay component was unknown until X-ray photography revealed its molecular structure: atoms of silicon, oxygen, and aluminium, often also iron and other elements, were arranged systematically in lattice-like sheets with unsatisfied negative electric charges enabling them to hold other atoms, and hold them firmly or weakly according to the conditions. This property was of special importance for the nutrition of plants, especially for the supply of potassium. The plant roots could take up only substances in solution, but these were liable to be washed out in the drainage water. Fortunately, the lattice structure of the clay enabled it to hold the potassium ions sufficiently strongly to save them being washed out, yet not strongly enough to prevent their passing into the plant roots⁶⁰.

622. In the recently created province in desert land, described in § 21, expansion of cultivation had to be eventually stopped as it did not pay, since the soil could not be “formed” quickly enough from the desert land, although it had been irrigated annually by the silt-laden flood water. It was bound to take much longer, if ever, to “form” the soil if Nile water were to be deprived of silt. Experience had shown that it was practically impossible to cultivate sandy soil in Egypt fruitfully if it was irrigated only by artesian water, no matter how long it continued. Even in land supplied normally with Nile water the arrival of the “red” flood water was hailed annually.

623. In § 402 Mr Allan, while agreeing that the loss of fresh silt in the irrigated land might well result in reduction of fertility, and the silt-free water emerging from the High Dam might cause erosion and degradation along the river course in Egypt, had maintained that the maximum expansion of cultivation could only be achieved by full over-year and annual storage of all flows. He concluded that either the consequences of complete irrigation must be accepted and its harmful effects mitigated by remedial measures as much as possible, or silty water must be wasted to the sea and irrigation limited to little more than its present extent. There were no other alternatives.

624. The Author had shown that full over-year and annual storage could be achieved without any harmful effects by using separate reservoirs for each storage. Practically no water could be wasted to the sea and the land would continue to be irrigated by silt-laden water in the high season as at present. He knew of no remedial measures that could economically compensate for the loss of silt. It was not a case of prevention

being better than cure but one where prevention was feasible and cure well-nigh impossible. On the other hand, permanent structures could be adequately protected against degradation.

625. Mr Lacey had said in § 301 that if the silt was as valuable as some people thought, it might be dredged or removed from the reservoir in some way or another and put where it was wanted. Realizing the impracticability of his suggestion, however, he had added that there were one or two fanciful suggestions lately in connexion with work in Egypt, and that indeed the Author had described the High Dam itself as a fantasy.

626. Mr Griffin thought (§ 469) that the loss of silt as a result of storage was an adverse factor to a limited extent, and wondered how far this question had influenced the dam design. His contention was that the only reason for the traditional design was to prolong the life of the dam.

627. The Author had pointed out that so far as silt was concerned annual storage dams were provided with under-sluices so that the silt-laden water might pass freely; thus the silt had no chance of being deposited in the reservoir as indicated in § 105. The date of filling the reservoir for storage, however, inasmuch as the degree of silt concentration depended on it, decided the life of the dam (§ 22). Incidentally, that arrangement suited the land from an agricultural standpoint, but that was about all, so far as the influence of silt on dam design was concerned. The value of the silt had already been discussed. The water emerging from the High Dam would be fairly clear with practically no silt content.

628. Mr Griffin had stated that there might be some means in future for keeping the heavier silt in suspension.

629. The only way to achieve this would be to provide mechanical stirrers all over the reservoir at prohibitive cost. Science knew of no other way. Even then, in still water no sooner would the silt be stirred in one place than it would be deposited in another, since still water had no carrying capacity to retain it in suspension for any length of time.

630. On the question of erosion, Mr Montagu had given instances of retrogression in the river course which had caused much damage (§ 358). The Punjab Government had constructed major barrages in the Sutlej River which formed immense silt-traps in the ponds above. The silt-free water emerging from the barrages had caused heavy erosion which had been serious at some places and disastrous at others. He anticipated similar retrogression resulting from the High Dam scheme necessitating adequate protection of the permanent structures on the river.

The Wadi Rayan project

631. With regard to the Wadi Rayan project, although it was never mentioned in the Paper that it should completely solve the over-year storage problem of the Nile, the main objections brought against it in the discussion were based on this false assumption. It had been stated in § 90 that an over-year storage capacity of 12 mld cu. m in the Wadi Rayan depression would have ensured a steady annual draught of 75 mld cu. m throughout the 20th century with the exception of the year 1913–14, which had the lowest discharge of 42 mld cu. m. In § 91 it was mentioned that an additional over-year storage of 12 mld cu. m would be available in Lake Tana, which would go a long way towards covering that year. Finally, it had been envisaged in § 181 that Lake Victoria, with its enormous over-year capacity of 200 mld cu. m would eventually supply any such deficit as the remaining 9 mld cu. m.

632. Mr Allan, who was evidently under the same wrong impression about the Wadi Rayan project, had said in § 398 that, with a storage capacity of 9 mld cu. m less 2 mld cu. m for losses, that is 7 mld cu. m, being added to the discharge of 42 mld cu. m of 1913–14, making a total of 49 mld cu. m, the Wadi Rayan project was altogether inadequate to meet the annual requirements of 70 mld cu. m, if such a year should be repeated. The storage of 9 mld cu. m, however, was set after deducting the losses as shown in § 116, so that the deficit in that year for a draught of 70 mld cu. m would be

19 mld cu. m only. This would be met later on by an additional storage of 3 mld cu. m in Wadi Rayan and 12 mld cu. m in Lake Tana, leaving 4 mld cu. m to be eventually met from Lake Victoria.

633. The Wadi Rayan Depression might be utilized for still higher over-year storage than stipulated above. It had been mentioned in § 108 that the total capacity of the depression was 20.75 mld cu. m. This was approximately equal to the total over-year storage required, namely, 21.5 as explained in §§ 58 and 59. By using 12 mld cu. m the capacity allotted to silt deposit would amount to 8.75 mld cu. m, which was sufficient for about 650 years, as mentioned in § 112. It could therefore be provisionally used for raising the over-year storage to (say) 18 mld cu. m during the next 50 or 100 years pending the construction of Lake Tana Reservoir and the Upper Nile projects.

634. With reference to Mr Allan's statement in § 398 that since the year 1913-14 had happened once it would be certain to happen again, the Author was, on the other hand, sure that it would never be repeated, because the circumstances in which it had occurred were unique. It was the year that followed the raising of the storage level of Aswan Dam from R.L.106 to 113, so that 7 m of rock and soil were submerged for the first time in their history, to what extent laterally no one would be able to say. This might account for the fact that the discharge in that year was 50% less than the next lowest year, and the probability of its recurrence was 1 in 240, that is, about once in the whole lifetime of the High Dam, estimated at 300 years.

635. Mr Black had gone a step further in assuming that the Wadi Rayan would provide a complete solution of the storage problem. He said not only that the over-year capacity of 12 mld cu. m was inadequate, but also that the annual storage of 39 mld cu. m, given in § 92, was inadequate. He had also overlooked the fact that this annual storage was concomitant with the Wadi Rayan and likewise did not provide for the ultimate requirements of annual storage which had been provisionally estimated in § 181 as 50.55 mld cu. m.

636. He had said in § 374 that the Author had based his study on the discharges of the 20th century, whereas in the discussion of Morrice and Allan's Paper³⁹ he and Dr Hurst had drawn attention to the fact that the Aswan series of years of the 20th century was a remarkable one and the probability of its recurrence was very low.

637. There were two or three good reasons for taking the discharges of the 20th century into account in that study. First, the mean discharge was lower than in the 19th century. Secondly, the discharge readings were accurate by common consent, while those of the past century were considered uncertain. Thirdly, they had been taken as a basis for sharing the Nile waters in the agreement recently concluded between the United Arab and the Sudanese Republics.

638. Mr Black objected next to the elimination of the year 1913-14 which, as the Author had shown, was only a provisional measure pending the execution of projects at Lake Tana and the Upper Nile.

639. In §§ 376 *et seq.*, he had proceeded to analyse closely the annual storage of 39 mld cu. m with his intimate knowledge of the hydrology of the Nile and its discharges year by year, and had devoted much time and space to proving that that storage would not cover the total requirement as a complete solution, which it was never meant to do. His analysis, however, was not without a constructive element.

640. He had pointed out that the mean natural flow of 15.4 mld cu. m taken by the Author for the 20th century was actually the mean from 1871 onwards, that the mean for the 20th century was only 13 mld cu. m and that it had fallen to 9.5 mld cu. m in the year 1921-22, thus making a deficit of 6 mld cu. m.

641. He had also referred to the standing practice of holding 20% of the annual storage water for July reserve which might sometimes reach 6 mld cu. m. Lastly he had mentioned that the 8 mld cu. m allocated to flood relief¹ had been based on the assumption that the Nile banks could stand for some time a discharge of 670 mld cu. m/day which was doubtful. He had concluded by saying that the project would entail a loss of 8 mld cu. m to the sea, and that it was altogether inadequate as regards over-year or annual storage.

642. The Author pointed out that even if all these deficits occurred simultaneously, which was a remote coincidence, they could all be met by an increase of annual storage even beyond the limits provisionally stipulated in § 181, if necessary, and being annual storage should not be taken as a reason for discrediting the Wadi Rayan project which was allotted to over-year storage, bearing in mind the principle of separate storages asserted in the Paper. Moreover, by increasing annual storage as outlined above no water need to be wasted to the sea. The anxiety about the inability of the banks to stand a high discharge could be relieved by proper co-ordination of regulation of the various annual and over-year reservoirs.

643. On the question of silt and erosion, Mr Black had said (§ 383) that the annual reservoirs would silt-up and desilt the Nile water as effectively as Sadd-el-Aali.

644. This was hardly a fair comparison, for with Sadd-el-Aali the land would be irrigated by clear water all the year round. Whereas with annual storage it would be irrigated by silt-laden water during the flood and high season as at present, since, at all events, annual storage could only begin after the land had received all its irrigation water requirements.

645. He had then gone on to say that there was no foundation in the Author's statement in § 22 that such reservoirs had come to be regarded in Egypt as an economic proposition serving a given purpose and having a definite economic life which came to an end when they had completely silted-up.

646. The High Dam itself had an estimated life of 300 years and Wadi Rayan 650 years. In 200 years the Hoover Dam in the United States would be an alluvial plain and the lives of many reservoirs was reckoned to be less than a century.

647. Mr Black's remarks in § 375 about the pumps remaining idle for a long period, applied equally well to the High Dam, as a reserve, for the same period. The inadequacy of seasonal power (§ 381), and other operational questions had all been dealt with in detail in §§ 119–128.

648. In § 466, Dr Lewis had raised the question of possible infiltration from the Wadi Rayan Reservoir to Fayoum Province.

649. As mentioned in § 109, this question had been finally disposed of by the thorough geological investigation carried out under the auspices of the Government, which was satisfied that no serious damage would ensue from that project and had actually proceeded to carry it through but it had been suspended owing to the advent of the High Dam proposal.

650. The depression would be filled with silt-laden water of high silt content, which was deemed unstorable. The silt would be deposited uniformly over the entire floor area and with the lapse of years would completely seal it. This would not be the case at the High Dam scheme, where the bulk of the silt would be deposited at the upper end of the reservoir (§ 598 *et seq.*).

651. An additional precautionary measure had been provided in § 127. In the initial stages the depression would be filled to a storage level of R.L.19 m only, which was 9 m below normal storage level. This operation might be continued as long as deemed desirable to allow the lower parts of the depression to seal up with silt.

652. Mr Griffin had maintained (§ 472) that the method of operating the pumping system of the Wadi Rayan would be expensive, since the pumps would be lying idle for long periods. This, however, was usually envisaged in any contingency scheme, provided as a reserve when required, and would be provided for in the cost of the scheme.

653. The cost of running the pumps in the Wadi Rayan scheme had been worked out in §§ 119–127 for all possible cases which might arise in their operation, which was not unduly expensive. Nor was the estimated cost of energy too low at 3 millieme/kWh. The actual cost of generation of energy at Aswan Dam hydro-electric scheme was 2 millieme/kWh, which was the price to be charged for *firm* power supplied to the fertilizer works from that scheme. The cost of *seasonal* energy supplied to Wadi Rayan was reckoned also at 2 milliemes/kWh, plus 1 millieme/kWh for the cost of transmission of power from Aswan to Wadi Rayan.

654. Mr Esson had proposed in § 345 that the Wadi Rayan depression might be

cultivated instead of being used for storage. There was no lack of cultivable land in Egypt, which was at all events more than could possibly be irrigated by the maximum available volume of Nile water. On the other hand, that depression did provide a unique site for an off-stream over-year reservoir.

655. The Yousfi Canal could be used, after widening, for filling Wadi Rayan Reservoir with water. This proposal had been previously studied and rejected because it would interfere with the present duties of that canal. Besides it could not be used for emptying Wadi Rayan Reservoir while performing those duties, so that in any case a special canal had had to be provided for emptying the depression, which would be used for filling it as well.

The Sudd pumping scheme

656. On the question of the pumping scheme of the Sudd region, Dr Hurst had stated (§ 276), that the general consensus of opinion had always been in favour of the "diversion canal" project which had been put forward by the late A. D. D. Butcher, and was finally adopted by the Egyptian Government.

657. It would appear from that statement, however, that Dr Hurst could not have read closely Butcher's original reports on the Bahr el Gebel Banking Scheme and the Jonglei Diversion Canal Scheme, both of which were his own. He had considered the former as the most straightforward and probably the cheapest, and having studied it in every detail he had favoured it for many years. He had reluctantly turned it down for the reasons given in the preface to those reports¹⁷ which were summarized in § 139. First, there were the difficulties and uncertainties associated with the remodelling of channels extending in marshy land composed for the most part of soft and decayed material, and the impossibility of guaranteeing the banked system during periods of high supply. Butcher had concluded by saying that those disadvantages were of sufficient weight to condemn the banking scheme, and consequently he had recommended his alternative scheme, the diversion canal, instead.

658. Those difficulties had been overcome, and the uncertainties removed, by the pumping scheme which would lower the water level in the channels and in the swamps at large. This would enable banking and remodelling to be carried out in practically dry soil which would remain dry until banking and remodelling were completed and, thereafter, to the point where no spilling would take place as mentioned in § 148 *et seq.*

659. Notwithstanding that definite plan and clear statement, to the effect that Bahr el Gebel would be dredged and remodelled throughout its entire length, Dr Hurst had worked on two mistaken and contradicting postulates in succession. In the first, he had assumed that there was no dredging or remodelling at all, and had calculated the drop-down curve of the pumps on that basis, from which he had concluded that the effect of pumping in lowering the water-level would not extend far enough in Bahr el Gebel. In his second postulate he had assumed that dredging and remodelling would be carried out only in the part extending from Lake No to Hillet Nuer, a distance of 223 km, as given in § 164, and had estimated the saving of losses resulting therefrom, while the rest of Bahr el Gebel would remain without remodelling. Consequently, spilling and losses would continue as they were at the present time. On the grounds of these conclusions at which he had arrived by incorrect and contradicting postulates, he had condemned the pumping scheme. Having given an outline of the argument he had followed, the details would now be given.

660. He had calculated the drop-down curve of the pumps in Fig. 14 on the assumption that there would be no dredging, as mentioned above, and had shown (§ 278) that the original drop of 3.4 m at Lake No would be reduced to half at a point 11 km from that lake and 0.2 m at a point 100 km from it.

661. Taking dredging into account, however, the bed level of the channel would be lowered to correspond to a slope of 5 cm/km, as specified in § 164, and the water-level would likewise be lowered, so that when dredging was completed in the part between Lake No and Hillet Nuer, a distance of 223 km, as mentioned above, the water-level in the channel would follow the line ABCDE, as shown in Fig. 21.

662. In order to trace drops in water level in the channel while dredging was still going on, that distance was divided into sections of 50 km each. It was obvious that whenever any given section was dredged out to shape not only the water level in that particular section would be lowered but the water level in the next section to be dredged would be lowered too. The stream in the undredged section above the dredged one would adjust its level, balancing its stock of energy so that after overcoming the frictional losses it would arrive at the end of that section or the beginning of the dredged one with minimum energy. In short it would follow a draw-down curve caused by the drop of level in the previously dredged section. Hence, the effects of dredging the various successive sections would be as shown in Fig. 21.

663. Before dredging had commenced while the pumps were in operation, the water level in the channel followed curve (1), which was the drop-down curve of the pumps, as obtained by Dr Hurst. After dredging the first section ending at B, 50 km from Lake No, the water level would follow AB and then continue along Curve (2). After dredging the second section ending at C, 100 km from Lake No, the water level would follow ABC and then continue along Curve (3), and so on. The drop of level at any given points, say B and C, could be obtained from Fig. 21, as shown below.

Observation point	B	C
Distance from Lake No	50	100
Drop in water level in channel, in metres:		
(a) Before dredging commenced	0.6	0.2
(b) After dredging the first 50 km	2.7	0.4
(c) After dredging the second 50 km	2.7	1.9

Thus, at C, 100 km from Lake No, the drop after dredging would amount to 1.9 m as compared with that obtained by Dr Hurst of 0.2 m, ignoring dredging.

664. As mentioned above, he had assumed in his second postulate that dredging and remodelling would be carried out only in the distance from Lake No to Hillet Nuer. He had stated (§ 279) that the losses incurred in that distance as calculated by Butcher were $1\frac{1}{2}$ mld cu. m, which would be all the saving effected by the Author's scheme out of 14 mld cu. m losses in the whole of Bahr el Gebel swamps (§ 277), thus ignoring the provisions made in §§ 148 *et seq.* that dredging and remodelling would be continued throughout the entire length of Bahr el Gebel system, with a corresponding reduction of losses.

665. Referring next to Bahr el Ghazal swamps, Dr Hurst said that they had received little attention as yet, whereas Bahr el Gebel swamps had been under study for 55 years, and he had suggested in § 283 that similar work should be carried out in the former swamps on surveying, etc., and collecting information about the people and their mode of life, which study would have to be done in any case whatever the project adopted for drainage.

666. He had mentioned (§ 282) that the rivers rising in the Congo Divide and, flowing into those swamps, were dry from December to May, thus coinciding with the Blue Nile regime, and consequently their water would be "untimely" and therefore useless unless adequate storage capacity was provided. He therefore suggested building annual reservoirs on their upper reaches for controlling their flow.

667. In § 179 *et seq.*, the Author had provided annual storage on the main Nile for dealing with Upper Nile water alongside with that of the Blue Nile. In view of the congestion of the White Nile which was bound to arise on account of the increased discharge from the swamps and the limited carrying capacity of that river, the suggestion of building dams on the rivers flowing into the swamps, if feasible, would be preferable to storage on the main Nile, inasmuch as it would relieve the congestion in the White Nile.

668. Finally, he deplored the high cost of the pumping scheme (§ 285), which, however, should compare favourably with that of the diversion channel which involved the excavation of about 200 million cu. m, for dealing with Bahr el Gebel swamps only.

669. Mr Griffin had remarked (§ 473) that the Author's proposal for dealing with the swamp losses of the Upper Nile appeared to have considerable merit. The Jonglei

FIG. 21.—DRAW-DOWN CURVES OF BAHR EL GEBEL AFTER DREDGING SUCCESSIVE STRETCHES AND FINAL REMODELLING

scheme selected after 50 years of patient plodding study, in which he (Mr Griffin) and many others were involved in varying degrees, was dispensed with.

670. He had added that the computed losses of Bahr el Gebel and Bahr el Ghazal swamps were about equal, but the ruling factor in shaping the solution was the topography of Bahr el Ghazal swamps. These could only be dealt with by pumping, and if such an installation was to be provided for these swamps they might as well handle the losses of Bahr el Gebel system, and so the Jonglei gravity scheme became unnecessary.

671. Mr Snelson's comments (§ 404) on the Author's pumping scheme had been confined to the drainage of Bahr el Ghazal swamps, which was in his opinion not a satisfactory solution for the following reasons. The Author had postulated in § 146 that it was possible to draw up 1 mld cu. m/month by the pumping system from those swamps (§ 405), while he estimated that the flow into the swamps might vary from 4 to 24 mld cu. m annually, and owing to the seasonal flow of the rivers feeding the swamps the inflow might vary from 0.1 to 3 mld cu. m/month. He added that since no provisions were made for control by storage or otherwise the swamps must have been expected to act as over-year reservoirs.

672. The Author said that there was no mention in § 146 that the annual mean discharge of 12 mld cu. m from the swamps would be spread uniformly over the year at the rate of 1 mld cu. m/month, nor was there any stipulation in the Paper to that effect, so that all the conclusions which Mr Snelson had drawn from that assumption had no foundation. The contention was that the pumping system would deal with the total annual flow as it came and pass it on to the White Nile for annual storage on the main Nile, together with the discharge of the Blue Nile as explained in §§ 179 *et seq.*

673. In §§ 407-408, Mr Snelson had proposed an alternative plan of building reservoirs on the upper reaches of the rivers feeding the swamps, and using the storage water for the irrigation of the land on the fringes of the former swamps or on any reclaimed parts thereof. The surplus would be transported by a main collector surrounding the swamps to Bahr el Gebel (Fig. 17), where it would be dealt with by means of additional diversion canals.

674. While he was agreeable to the building of annual reservoirs on the rivers flowing into the swamps, the Author could not agree to the main collector proposal which was open to the same objection as the diversion canal of the Bahr el Gebel system, if not more, because of the double handling of the water, which would cost at least twice as much per unit volume, as in Bahr el Gebel system. Why go to all this trouble? There was a vast depression which embraced Bahr el Gebel and Bahr el Ghazal swamps. It was neither deep enough to form a natural lake in the course of the river as in many others, where there were only evaporation losses, which in the present case would be compensated by rainfall, nor was the ground sufficiently elevated to prevent the growth of those swamp plants which double or treble the losses by transpiration. When gravity was thus hampered by peculiar land configuration from exercising its force to maintain flow, the alternative was to maintain flow by mechanical means, as in lift irrigation and drainage. The only difference was one of scale. Yet in the Central Valley, U.S.A., 1 million acres were being irrigated with a lift of 100 m.

675. It would seem that the pumping scheme was attacked merely out of prejudice against its novelty rather than from any genuine objection. The specialist irrigation engineer who generally depended on gravity for the flow of water in channels with more or less natural slopes, might be prepared to go into a lot of trouble and expense to induce it to come into play, by costly and roundabout diversion channels and main collectors instead of adopting the simple and straightforward course of pumping. In the present case the energy required for this purpose would be provided by a self-supporting hydro-electric project.

676. Finally, Mr Snelson had proposed the construction of a series of small dams between Nimule and Rejaf instead of one dam at Bedden, as envisaged by the Author in § 173, and developing the same head. The Author thanked him for that proposal which seemed more in harmony with the topography of that territory.

677. Dr Lewis had referred to the difficulties which were likely to be encountered in passing the discharge of the swamps through the White Nile.

678. These difficulties were bound to arise whenever an increase of discharge from the Upper Nile was contemplated from any scheme whatever. In § 176 and § 179 *et seq.*, ways and means had been discussed for dealing with that question.

679. He had expressed some anxiety about the pumped water causing a breach in the banks of the White Nile. The safety of the banks could be ensured, first, by strengthening, and second, by the flexibility of the pumping system in regulating the discharge into the White Nile.

680. In this connexion Mr Hunter had objected in § 340 to the Author's statement in §§ 176–177 that the erection of Gebel Aulia Dam was a mistake which he thought had reflected on the ability of those who conceived it and carried it through. He had added that it had served its purpose for 50 years.

681. The Author said that his statement referred to its effect in reducing still further the gradient in the White Nile which was already low, and so had reduced its carrying capacity considerably. This disadvantage was probably not so obvious 50 years ago as it was now, when an increase of the Upper Nile discharge was being seriously contemplated. No doubt Gebel Aulia Dam had served its purpose for the past 50 years, but so would any other dam built on a more suitable site; for instance, such as Merowe without its drawbacks.

682. Mr Esson had expressed some fear in § 342 that by the reclamation of the Sudd swamps the reduction of evaporation and transpiration might unduly dry the atmosphere and so encourage southward advance of the Sahara Desert into the former swamps.

683. There was, however, heavy rainfall in that region which would guard against the encroachment of the desert climate.

684. Mr Black had contended (§ 385) that a reading of "The Nile Basin", vol. 534, and a visit to the Sudd region would have convinced the Author that his project for draining the Sudd region was impracticable.

685. The Author had read not only that book which, as mentioned in its preface, summarized and discussed a large mass of hydrological material collected during the previous 30 years, but he had also read the original reports and publications from which that book had largely been drawn. Moreover, the Author had travelled thousands of miles in that region by steamer, by car, and on foot, and had inspected not only the principal channels of Bahr el Gebel, Bahr Zeraf, and Bahr el Ghazal, but also several of the rivers which fed the swamps. Indeed it was a study of the topography of that region which had convinced him that the pumping scheme was the simplest and most practical solution.

Miscellaneous

686. Mr Griffin had said in § 470 that the Author's statement in § 94 about the recent Nile waters agreement tended to be confusing, and he had tried to clarify as followed. He had assumed that the agreement had provisionally given Egypt and the Sudan equal shares and that Egypt had elected to earmark the losses of 10 mld cu. m out of her share.

687. This postulate might help to explain the vast inequality of the actual shares. But the original shares which he had given in Table 22 as 16·5 mld cu. m for Egypt, and 14·5 mld cu. m for the Sudan were not equal, which would invalidate that postulate. Besides, he had made a mistake in that Table either in the sum of the first column which should read 65·5 or in the sum of the last item which should read 74.

688. The basis of that agreement, however, as given in the official text was:—

- (a) That the water used at present, namely 48 mld cu. m for Egypt and 4 mld cu. m for the Sudan, constituted their established rights.
- (b) That the net benefit of the Sadd-el-Aali Reservoir should be calculated on the basis of the mean natural river supply of 84 mld cu. m. The established rights, as well as the losses of 10 mld cu. m, should be deducted from the

mean discharge and the balance of 22 mld cu. m should be divided as 14.5 mld cu. m for the Sudan and 7.5 mld cu. m for Egypt.

Hence, the postulates mentioned by Mr Griffin were neither explicitly nor implicitly observed in the agreement.

689. The provisions of that agreement might be tabulated thus:—

	Egypt	Sudan	Total
Mean Nile discharge			84
Mean Nile discharge (less losses)			74
Established rights	48	4	52
Division of balance	7.5	14.5	22
Total share	55.5	18.5	74

This was in agreement with § 94.

690. Thus, while Egypt had to bear the entire cost of the High Dam, amounting to £404 million as estimated by the World Bank, and pay to the Sudan £15 million for rehabilitation and compensation for the land to be submerged, she got only one-third of the benefit from the dam and the Sudan got two-thirds.

691. Mr Griffin's statement in § 471 that the large power generation from the High Dam was ample compensation for Egypt had merely confused the issue. For the main object of the dam was to increase irrigation water supply for the expansion of cultivation, for which the Nile was the only source. Electric power could always be generated in thermal stations in Egypt at a price comparable, if not cheaper, than water power. The Aswan Dam hydro-electric scheme was an exception, because the dam had already been built and therefore its cost was not charged to power generation.

692. Mr Gruner had referred to the statement made by the international commission in § 104 that a breach in the High Dam might be disastrous to Egypt. He had said (§ 482) that there would not be such a risk if several dams were used in place of one high dam. Not only was the fate of most of the population linked up with the dam, but it was also a gigantic undertaking to concentrate all irrigation water requirements in a single reservoir.

693. In § 388, Mr Kennedy had referred to the possible increase of the normal silt load carried by the river due to sandstorms, mentioning its usefulness as a make-up for bed erosion, and its possible arrest when the High Dam was built. This factor was of particular interest since Khamsin winds which generally cause sandstorms blew from the south to the north, although it would be difficult to ascertain its extent.

694. Mr Cochrane believed (§ 314) that the drop on Nile discharge in the present century of 22.5% could be attributed to an overall reduction of rainfall by a mere 2% or so, because in low-yield tropical catchments run-off was proportionately more variable than rainfall. On the other hand, however, such persistent reduction in rainfall would also have caused a significant change in the ecology of the catchment, and that was not likely to have passed unnoticed.

695. The Author had pointed out that cyclic variation of rainfall was more difficult to prove. Given a constant or presumably constant solar radiant energy it was difficult to explain why should there be cyclic variation of rainfall at all. Even if it were possible to prove the existence of such a cycle from actual observations, unless it could be traced to some physical agents at work in a cyclic order, it was likely to be a mere coincidence. The only conceivable cause of variation of solar heat was sunspots which followed a cycle averaging about 11 years, and although it had been proved to cause corresponding cyclic magnetic and radio disturbances, there was no definite evidence of any similar effects on the sun's radiant heat. In the circumstances cyclic variation of rainfall would be practically impossible, for it would implicitly involve the assumption of crediting the atmosphere with enormous capacity of storing moisture over half the cycle of low rainfall to be precipitated in the other half of high rainfall. This might be admissible for 1 or 2 years in a random rather than cyclic order.

696. Mr Cochrane had referred to the contribution of Mr Robertson in the discussion on the Nile Paper by Morrice and Allan³⁹ regarding the persistence of Colonel Rawson's cycle in the flow of the Nile and its tributaries.

697. Mr Robertson had again drawn attention to this subject in §§ 444 *et seq.*, and by using the discharges of the hydraulic years given in Appendix I had produced remarkable diagrams showing that they followed Rawson's cycle of 9 years fairly closely.

698. In § 326, Mr Cochrane had compared Colonel Rawson's cycle of 9–10 years with his own shorter cycle and had arrived at the conclusion that Rawson's cycles were more predictable than his own and that the magnitude of variation was more regular and more definite.

699. In a previous discussion⁵⁹, Mr Cochrane had asserted that the Smithsonian solar constant, a measure of solar energy, was related to the rate of change of sun-spots irrespective of their number and that it was highest when the sun-spots were changing most rapidly. This was a very important result which might be taken as a basis for research on cyclic variation of rainfall. For it was conceivable that the rate of change of solar radiant heat was more likely to cause atmospheric disturbances and variation of rainfall rather than the amount of radiant heat itself. The Rawson cycle which was close to the sun-spot cycle would make a plausible hypothesis for further research in that direction.

700. Finally, Mr Cochrane had said in § 318 that the Author had diverted the Nile from the statistical netherworld through which it had apparently flowed for so long. On a previous occasion Mr Cochrane had called upon Dr Hurst when discussing his paper⁵⁹ to cast away the statistical heresy because he thought it hid more than it revealed.

701. Indeed, he had expressed the sentiment which the Author and some of his veteran colleagues had always felt when they saw the Nile, the life-stream of the country, being dragged into that statistical netherworld which was in all respects contrary to the time-honoured irrigation policy, and indeed to established engineering methods.

702. The Paper would have achieved its object if it had succeeded in delivering the river from that statistical tangle in which it had been wrapped up which had delayed irrigation projects for the past decade during which time the population had increased by about 20%, without any increase of the cultivable area. It was the Author's firm conviction that if the High Dam was to be built it would have to be scrapped eventually after delaying irrigation progress for some years and running the country into a considerable foreign debt.

703. Mr J. Guthrie Brown had observed in § 332 that the cross-section of the High Dam, shown in Fig. 5, was an old proposal which had been modified in many respects by the Board of Consultants and his firm, and he understood that there had been further substantial modifications by the Russians. That was true, for the Paper had been written some years ago. Fig. 22 showed the latest cross-section which had been recently released for publication together with further information relating to the construction of the High Dam^{61, 62}, which enabled the Author to give an authentic reply to Mr Guthrie Brown's comments.

704. He had mentioned in §§ 328 and 329 that the Author had considered the dam to be to some extent a hazardous undertaking. He had pointed out that the design had been developed by a Board of Consultants consisting of six of the most eminent engineers who were satisfied that the dam could safely be constructed, and he had added that only a bold man would disagree with their decision.

705. The Author stated that he had made no comments on the design of the rock-fill dam itself, but had merely quoted in § 103 the guarantees given by the Board of Consultants, and observed that they were not as good as might have been given for a masonry or concrete dam built on a rock foundation. Since Mr Guthrie Brown had mentioned the question of the safety of the dam, however, the Author would give below his own views about it. It was stated in § 97 that the site of the dam was a U-shaped cut through granite, about 200 m deep below bed level, filled with products of erosion containing coarse sand, gravel, silt, and clay with isolated boulders of granite. The following description of the construction of the rockfill dam and its foundation had recently been published^{61, 62}.

706. The whole extent of the main dam foundation would be covered with a layer

of compacted dune sand about 25 m (82 ft) deep. The rockfill dam above this layer would have a core made of Nile silt, resting on a vertical grout curtain descending in the pervious bed of the river down to the bedrock. It was this curtain in particular which had to be constructed entirely below the river-bed rather than the rockfill dam itself above the river-bed which had given cause for anxiety about the safety of the dam.

707. The curtain in question would extend across the river underneath the dam through a distance of 4.4 km (2.5 miles) with a width of 60 m (200 ft), being well anchored into the banks, and would descend in the pervious subsoil to a depth of 210 m (690 ft) until it struck natural rock. This was about 40 m (130 ft) deeper than the world's present deepest grout curtain, that under the Mission Dam in British Columbia.

708. The object of that curtain was to plug the voids in the various layers of sedimentary material throughout the entire depth of the pervious bed down to the natural rock. This object would be achieved by injecting a slurry of clay with a slight admixture of cement and some chemicals.

709. In order to test the efficacy of the injection process two tests had been carried out at site. The first in the fine sand bed which extended immediately below the river-bed to a depth of about 50 m (164 ft), see Fig. 22. It was found that the permeability was reduced by injection seventeen times. The second test was performed in coarse sand which predominated the remaining layers underneath. The permeability was reduced one hundred times. These results were considered favourable for the construction of the dam⁶¹.

710. No information had been given about the final permeabilities reached. At all events, there was nothing remarkable about those results with reference to the initial permeabilities in either case to warrant reliability of the grout curtain on which the entire safety of the dam depended.

711. Moreover, it should be borne in mind that all injection operations to be carried out in that curtain throughout its length, width, and at various depths should eventually form together one continuous, monolithic, and impervious wall with no flaws whatsoever for the infiltration water to creep through—a task which, in view of its extraordinary depth, was well-nigh impossible to achieve.

712. It was probably on account of this and other uncertainties, which were bound to occur in the construction of a curtain of that magnitude buried as it was to that great depth beyond all possible human observation and control, that the Board of Consultants could give only those vague guarantees mentioned in § 103, namely, that the dam was as safe as the safest of rockfill dams built on sand. And what was the value of such a guarantee for a country whose entire future and very existence depended on that dam? Yet it was about as much as any engineer could have given under the precarious conditions of the site.

713. Realizing the catastrophic danger to which Egypt would be exposed in the event of breach of the dam which would inundate the whole country, the Board of Consultants had recommended that in the event of war the reservoir should be emptied to R.L.150 m, and that the level be further reduced to R.L.130 in the event of atomic bombs being used. The corresponding water content of the reservoir would be 40 mld cu. m for R.L.150 and 10 mld cu. m for R.L.130.

714. Hence, if war broke out when the reservoir was full to, say, only 100 mld cu. m out of its total capacity of 130 mld cu. m, and assuming a maximum permissible discharge of 670 million cu. m/day, which Mr Black had stated the river could not possibly take at a short notice (§ 378), then in order to carry out that recommendation it would take 90 days to empty the reservoir by 60 mld cu. m to R.L.150, and 135 days to empty it by 90 mld cu. m to R.L.130 in the event of atomic bombs being used. If war broke out when the reservoir was full up to its total capacity of 130 mld cu. m, it would be necessary to add 45 days to each of the above emptying periods which would thus be raised to 4.5 and 6 months respectively.

715. Finally, it should be mentioned that the present site of the High Dam had been selected mainly because of the granite river banks for piercing the diversion tunnels

through. Now that those tunnels were being replaced by an open channel by the Russians, which had reduced the loss of head from 65 to 40 ft⁶¹, it was difficult to see why that exceptionally bad site was still adhered to.

716. A concrete dam could be constructed on solid rock at the Second Cataract (Semna Gorge) at a much lower cost, with a shorter delay, and with an infinitely better guarantee than for the rockfill dam in the present site. Not only would that fanciful paraphernalia of injections be dispensed with, but the town of Wadi Halfa and the historic monuments of Abu Simbel, etc., would be saved from drowning. The diversion channel would be dispensed with in this case, since the power station would be incorporated in the dam. This would eliminate the losses incurred in the channel and so raise the power generated by about 20%.

717. This suggestion, however, should not be interpreted as an approval of the High Dam scheme, which the Author had rejected entirely in favour of the separation of over-year from annual storage.

718. In the light of the preceding discussion definite proposals could now be put forward for providing the necessary storage capacity to ensure a constant annual draught of 72 mld cu. m as guaranteed by the High Dam, while at the same time eliminating its drawbacks.

719. Referring to § 76, a total storage capacity of 65·2 mld cu. m had been envisaged to ensure an annual draught of 72 mld cu. m, as follows:—

- (1) An annual storage of 26·2 mld cu. m to be provided on the main Nile (§ 75).
- (2) An over-year storage of 9 mld cu. m (§ 67).
- (3) A dead storage of 30 mld cu. m to be provided for a silt trap.

720. In accordance with the principle of the separation of annual from over-year storage and placing the latter at Wadi Rayan, the dead storage of 30 mld cu. m would be dispensed with. The remaining annual and over-year storages would now be dealt with more fully.

721. *Annual storage.*—The annual storage should be raised to 35 mld cu. m in order to increase the annual draft to 75 mld cu. m and to take into account the constructional observations made by Mr Black in § 376 *et seq.* This capacity would be distributed as follows:—

- 25 mld cu. m at Semna Gorge at the Second Cataract.
- 5 mld cu. m at the present Aswan Reservoir.
- 5 mld cu. m at Roseires.

Alternatively, if the present site of the High Dam were insisted upon this dam could be built for a storage of 30 mld cu. m leaving 5 mld cu. m to be taken up by Roseires Dam.

722. *Over-year storage.*—The proposed 9 or 12 mld cu. m at Wadi Rayan could be retained if the lowest year 1913–14 were ignored, and the next lowest year 1899–1900 were taken instead (§ 67). It had been shown that the probability of recurrence of the lowest year was 1 in 240 and that in fact it was unlikely to be repeated (§ 634).

723. In accordance with Hurst's formula as corrected by the Author, however, an over-year capacity of 21·5 mld cu. m would be sufficient to cover all possible low years (§ 58).

724. It had been shown in § 633 that the total capacity of Wadi Rayan of 20·75 was about sufficient for the over-year capacity of 21·5 given by Hurst's formula, were it not for the necessity of providing a space for silt deposit in Wadi Rayan depression. By allotting 12 mld cu. m to over-year capacity the remainder of 8·75 mld cu. m would be sufficient for 650 years, that is, at the rate of 1·35 mld cu. m per 100 years. Hence, it was possible to raise the over-year storage in Wadi Rayan to 18 or 19 mld cu. m during the next 50–100 years pending the construction of Lake Tana or the Upper Nile storage projects.

725. It was thus obvious that Wadi Rayan offered a large latitude of flexibility to meet almost any conceivable contingency. The over-year storage should be limited at the outset to 12 mld cu. m, to be raised in future should it prove necessary.

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