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Planning for the ultimate hydraulic development of the Nile Valley†

by

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and

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Discussion

Mr Gerald Lacey (Consultant, Sir Murdoch MacDonald and Partners) said that he would have been glad if the Authors had found it possible to preface the Paper with a very brief history of previous attempts to solve the secret of the Nile. Sir Murdoch MacDonald, who had been President of the Institution, had written many years ago his classic Paper[5] on Nile Control, and many others, both hydrologists and engineers, had dreamed of the ultimate control of the Nile. The present Paper was singular in having at the end no bibliography. Perhaps the Authors would repair that omission later, because many engineers were traditionists and liked to know a little of the history and the background of a subject. The Authors had described a very fine scheme, but it had had its humble predecessors. There was a reference in the Paper to vol. 7 of "The Nile Basin". In the introduction to that work[6] would be found these words: "An attempt to see the final development of Egypt and the Sudan up to the limits of the water supply and the projects necessary for this."

139. In the present Paper that intention had been brought to fruition by means of the labours of engineers from the Sudan. It was a fitting tribute from the Sudan to Egypt. It was right that Egypt, having produced an invaluable collection of hydrological data, should have that debt fully repaid by the Sudan engineers who had produced the plan now being discussed.

140. There were several aspects of the investigation which he would like to mention. There was the use of the electronic digital computer as an aid to the hydraulic planning of large river basins, the value of which had been very fully established. The Authors had fed into the machine invaluable hydrological data HD which had taken nearly a half century to collect, the plan P, and the equations E, in a special form. From these three raw materials they had obtained the end production X and Y, and also α and β, factors such as the demands for water by Central African countries and possibly by Ethiopia.

Effectively:
$$HD+P+E = X+Y+\alpha+\beta$$

141. The plan was very different from that which had been put forward in vol. 7, because the concept of the great Aswan Dam had superseded earlier and smaller storage schemes. At a time when he had been associated in a small way with two of these projects he and his colleague, Mr Griffin, had investigated the Merowe (4th Cataract) Dam site, where it had been hoped to provide a storage reservoir holding about 9 milliard cu. m, and also the possibility of developing the great Wadi Rayan depression, which might produce an extra 4 to 5 milliard cu. m of water a year. With the

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† Proc. Instn civ. Engrs, vol. 14, p. 101 (Oct. 1959).

[5] References 5–17 are given on p. 316.

construction of a high dam to hold 100 milliard cu. m it would be unnecessary to execute those small storage works, except for hydro-electric development.

142. In vol. 7 there would be found a forecast of the agricultural requirements of Egypt of 58 milliard cu. m. According to the latest figures quoted in the Press, the share of Egypt was to be 55·5 milliard cu. m and that of the Sudan 18·5 milliard cu. m. That was a ratio of 3:1, and therefore it fell within the scope of the two Tables SOA-I and SOA-II of the present Paper, which ranged from ratios of 2 to 3·5. The plan, therefore, had been very skilfully contrived; but those who wanted the background and were anxious to study the subject would find, if they read vol. 7, that it provided an admirable picture.

143. It would have been interesting if the present Authors had given some idea of the range of water level in some of the sources which they incorporated. At the time that vol. 7 was written there had been to the south Lake Victoria, Lake Kioga, Lake Albert, in the central region, Lake Tana, and then northwards to Aswan there had been very little. Now there was, from the extreme south, 120 milliard cu. m from Lake Victoria, 10 milliard cu. m from Lake Kioga, another 100 milliard cu. m from Lake Albert, and 100 milliard cu. m at the new Aswan Dam. Upstream of the new Aswan Dam there was the Semna reservoir holding 25 million cu. m. In addition to that, there was in the Sudan not only the Roseires reservoir but the entirely new Upper Blue Nile reservoir, about which it would be interesting to hear a little more, with 18 milliard cu. m, and also Lake Tana, in Ethiopia, with 15 milliard cu. m. It had always been considered in the past that this lake could produce only 5 or 6 milliard cu. m, but the idea of emptying that lake by means of a tunnel was a bold concept. In a phenomenal year such as 1913 the storage of Lake Tana would be providential. It was stated that it would contain 15 milliard cu. m and in a very bad year could be entirely emptied. The topographical reasons for restricting rises in the water level had been given, but Mr Lacey would like to know by how many metres the water level would drop in such a year as 1913, and whether or not the matter had been fully discussed with Ethiopia. He imagined that in such conditions it might be possible to reach the small islands in the lake, some of which had ancient churches on them, dry-shod.

Mr R. L. Fitt (Partner, Sir Alexander Gibb & Partners) said that the Authors had had the advantage of a magnificent set of records from the volumes of "The Nile Basin", without which the establishment of the programme set to the machine would have been difficult if not impossible. They had taken 48 years of records from 1902 onwards for which full hydrological data were available and which included not only the abnormally low year 1913–14, but also the high flood of 1946. They had the satisfaction of knowing that the overall annual discharge measured at Aswan over the preceding 30 years had been higher than for the period studied and, by proposing that the annual volume of irrigation water to be shared by Egypt and the Sudan should be based on the mean value over the previous 5 years, they had provided an additional safeguard that overyear storage would not be withdrawn.

145. There was no river in the world that had such a remarkable set of records as the Nile. Not only had the Authors had available to them discharges taken at various points but they had also been able to compute with considerable confidence such factors as evaporation losses at various points in the river system and time lags from the sources of the two main rivers down to Aswan. Were the Authors of the opinion that there were many other river systems in the world which would be amenable to the same type of treatment, and with comparable accuracy? If so, would they be prepared to express a view as to the minimum number of years of records which they would consider essential for the purpose? Would they be concerned, for instance, by a shortage of meteorological data from which to compute likely evaporation and transmission losses?

146. The calculation establishing the value of the year's allocation of irrigation water to Egypt and the Sudan had been made each year at the end of June as at Lake Victoria, a date which was equivalent to about the end of July at Sennar. Would not there have been some advantage in establishing the amounts, say, 1 month earlier, in

order to facilitate the pre-planning of the irrigation programme for the agricultural year, which in the Sudan would start in July?

147. §§ 45–51 described impossible situations which could arise in the course of the calculations and explained the methods of dealing with them. Among these situations might be cases in which the flow in certain parts of the river ceased altogether or even became negative, or the contents of a reservoir fell below the minimum or rose above the maximum allowed. In such circumstances the computer either stopped, so that the difficulty could be investigated, or calculated the figures again in such a way as to correct the impossible situation. During such a process the machine might have to go back to avoid the difficulty or to correct an infringement of some particular condition. The computer had the advantage that it could retrace its steps if something went wrong. That was where the Authors and their mathematical collaborators had used not only ingenuity and engineering judgement but also foresight. Unfortunately, this could not always be done in nature. Once the water had passed down the river it could never be brought back. In the basin of the Upper Blue Nile, for instance, it was improbable that adequate notice could ever be given that the run-off was likely to be low. The steps taken by the computer to make good such shortages might have been performed at some point in time prior to that at which the shortage occurred. In practice, therefore, would not it be advisable to have a factor of safety by providing ultimately rather more overyear storage than the computations suggested?

148. It was one of the features of the Nile Valley Plan that a shortage in the Blue Nile could be made good by drawing on Lakes Victoria and Albert. Here there was a difficulty in that in terms of time conditions on the Upper Blue Nile were some 3 weeks ahead of those in Lake Victoria. If a shortage developed in the Blue Nile which prevented the river making its due contribution to the combined flow of the main Nile at Khartoum, the time lag between conditions at Lakes Tana and Victoria might make it difficult to correct the situation in time by drawing more water from the Uganda lakes. This was an important point in considering hydro-electric developments.

149. Some of the minimum discharges used in the computations were a little puzzling. Below Lake Albert the first analysis produced a minimum discharge of zero and the second analysis a discharge only slightly higher. The Authors had added a footnote to the effect that the minimum value could be raised to 0·75 milliard cu. m/month. Would not it have been possible to accept this minimum in the first instance and thus ensure that this reach of the river would remain navigable, as it was at present? In the case of the Jonglei Canal, note (*b*) to Table 11 stated that a minimum of 0·57 M/M could be arranged. Was this sufficient to ensure navigation in the Jonglei Canal, and at the same time would it be sufficient to inhibit the growth of weeds?

150. Turning to Lake Victoria, the 48 years investigated had produced a variation in reservoir capacity of 120 milliard cu. m. This was a variation of lake levels within the 2-metre extreme range recorded under natural conditions of discharge. As a result of the construction of the Owen Falls Dam an additional 1-metre range of storage was available. To what extent could this reserve overyear storage be used further to improve long-term regulation?

151. The Nile Valley Plan included a number of proposals which Mr Allan had mentioned, and even this formidable list did not necessarily cover the whole range of possibilities. For instance, had the Authors considered the possibility of reducing evaporation losses by lowering the level of Lake Kioga, and had they considered the practicability of canalizing the Bahr-el-Ghazal, which, in spite of its immense catchment area with comparatively heavy rainfall, contributed only a very small quantity of water to the Nile?

152. As Mr Lacey had pointed out, the ratio of 3 to Egypt and 1 to the Sudan lay between the two alternatives described in the Paper. The Authors had pointed out that the two analyses, using widely different values of X and Y, had produced very much the same result in respect of overyear shortage. Were they convinced that this was not a chance result? One would normally be diffident about plotting a curve with only two points.

153. The question of potential hydro-electric power provided an example, in Mr Fitt's view, of the preliminary nature of the information provided by the machine. In the case of Roseires, the range of both upstream and downstream levels was very wide, and both there and at Sennar there were certain critical conditions at flood-time which imposed restrictions which were not disclosed by a computation based entirely on rate of discharge and difference in head. This would seem to emphasize the need for careful and critical study of each project as it came up in the programme of development.

Dr H. E. Hurst (Scientific Consultant to the Ministry of Public Works, Egypt) observed that the use of an electronic computer to devise a method of working a combination of projects for the utilization of the waters of the Nile was a new venture and introduced a very powerful tool into the study of Nile conservation projects.

155. He had already shown[7] that for a series of annual values of a river discharge (Q) the storage R required to maintain the discharge equal to the mean was given by:

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

where N denoted the period of years, σ is the standard deviation of the discharges, and K a variable index. The storage R was, in fact, the range of the curve produced by plotting the successive sums of the departures of Q_1, Q_2, etc. from their mean against the number of years 1, 2 . . . N. That equation held good for many natural phenomena other than river discharges (rainfall, temperatures, tree rings, varves, etc.). The index K varied from set to set of observations, but had a mean value of 0·73 between extremes of 0·46 to 0·96. Altogether 105 different phenomena had been examined, producing 813 sets of observations and values of K. The shortest sets contained 30 years and the longest 2,000. The mean values for different classes of observations did not depart far from 0·73, and so far as K was concerned the classes were not distinguishable one from another. The variation of K from set to set raised the question whether K tended to be constant throughout a very long record; were the values of K related to their predecessors or were they independent of each other? To test that, a 900-year record of Californian Redwood tree rings, divided into consecutive 50-year sets, had been examined by correlating K for one set with K for the next. The number of sets (18) was not really large enough for a correlation. The coefficient had been found to be $-0{\cdot}21 \pm 0{\cdot}09$ and was not large enough to have any significance. A long record of 4,000 years of varves divided into 100-year sets had given a coefficient of $-0{\cdot}07 \pm 0{\cdot}11$, which again was not significant. It could be concluded, therefore, that values of K for different samples of the same phenomenon were independent of each other, and were therefore random events. Consequently, if a set of observations covering 50 or 100 years was available and it was decided to choose a value of K for future use, the choice would fall not on the value of the single set of observations, but upon the mean value from the 800 cases which had been computed. Fig. 19 showed a frequency curve for values of K taken from reference 7. It would be seen that the distribution was approximately Gaussian, like that of many random variables, and was also random.

156. The present Nile Valley Plan drew up working arrangements for the combination of projects, and the machine applied them to the data of discharges for 1905–52. One result which it had produced was the storage capacities in the various reservoirs, which were required to equalize approximately that particular sample of years. The value of K for the annual discharge of the Nile at Aswan, without abstractions for irrigation in the Sudan, was 0·53 (see Fig. 19). It would be seen that that value was nearly at the lower extremity of the curve. The probability of a value as low as that was about 1/54, for it had happened fifteen times in the 813 values so far computed. If only periods of 40–60 years were considered it was found that values of 0·43 or less occurred four times in 280 samples. Turning to the long series of nearly 1,100 years of Nile flood heights recorded at Cairo, where K has been computed for consecutive centuries, the lowest value was found to be 0·58 and occurred only once. The mean value of K

for 99 sets of floods was 0·75, which was not very far from the mean for all phenomena, showing that the Nile did not differ from the other natural phenomena from which the mean value of *K* was calculated. It was safe to say that such a sample as that given to the machine would not happen on the Nile on the average as often as once in 1,000 years. A low value of *K* meant a low value of the storage which would be required to make the best use of the available water.

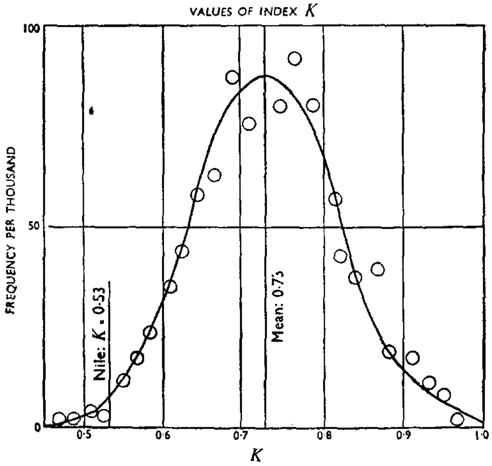

FIG. 19.—FREQUENCY OF INDEX *K*

157. It was clear, therefore, that valid conclusions as to future requirements for long-term storage to equalize, to the greatest extent possible, the flow of the Nile could not be drawn from such an unusual set of years as 1905–52.

158. If a series of years happened in which *K* was about the average (0·73), the storage tabulated in the Paper would be quite inadequate to equalize the discharge, and it would be necessary to spill water to sea. That would be inevitable in a series of years like 1870–1898, because as far as was known at present it seemed probable that the storage capacity did not exist in the Nile basin to enable full use to be made of the flow from 1870 to the present day.

159. It might again be emphasized that there was no such thing as a fixed long-term mean. Means, standard deviations, and values of *K* could all vary, even for periods of 100 years, as would be seen from Table 12 in reference 7. The problem to be solved was how to make available for use the largest possible part of the mean supply of a future series of years, whose mean, standard deviation, and order of occurrence were all unknown.

160. Dr Hurst drew attention to the importance of flood protection to Egypt, where a very high flood was extremely dangerous. In the twentieth century, there have been two dangerously high floods, but in the last 30 years of the nineteenth there had been four floods higher than either of them. In the highest the peak month had been 100 million cu. m/day or 10% higher. During that 30-year period, thirteen floods had been high by present standards, as compared with five in the first 52 years of the twentieth century.

161. Everyone in Egypt was aware of that danger, and in the High Aswan Dam Project 30 milliards in excess of the 100 milliards, which were for long-term storage and silt retention, had been allotted for flood protection. The Nile Valley Plan gave the capacity of the High Aswan Dam at 100 milliards and in addition, a reservoir of 25

milliards at Semna. Those figures, however, arose from computations based on the years 1905–52, which had been shown to give a low value for the required long-term storage capacity. The series of high years from 1870 to 1898 required special consideration from the point of view of flood protection. In those years the average annual discharge had been 110 milliards against 84 milliards in the years 1905–52. Future conditions in Egypt in flood time would be different from what they had been in 1900, since the basins, which had helped to reduce the flood peak, would have disappeared, and in many years very little water would flow through the Nile branches in the Delta to the sea, thus increasing the difficulties of maintenance of the banks. The High Aswan Dam was the last line of defence for Egypt against floods and the last means of rectifying mistakes or calamities upstream. The 30 milliards for flood protection was therefore essential.

Mr G. M. Binnie (Senior Partner, Binnie, Deacon, & Gourley, Consulting Engineers, London) commented on Mr Allan's statement in introducing the Paper that the methods used in the Nile studies described could be applied on other rivers and said that the experience of the Hydrological Survey of Iraq during the past 2 years had confirmed this belief. The purpose of that survey had been to investigate by means of operation studies five different potential reservoir sites on the main river and three on the tributaries. These sites had been investigated in combination and singly. Mr Allan had emphasized the need for data. Mr Allard, who was Director-General of Irrigation about 30 years ago, established the river gauge network and initiated the gauge readings which had been maintained in Iraq ever since, and for which Iraq today should be very grateful to him. Without his pioneer work, all the subsequent work would have been quite impossible. The Hydrological Survey had been fortunate in having 27 years of records of a very high standard in many respects on which to work.

163. In getting the work started they had, of course, asked the Authors to show them and teach them what had been done on the Nile, and the Authors had played a very great part in adapting the Nile methods to the Tigris. The Tigris differed in many respects from the Nile. It rose in Turkey and flowed into Iraq, and had four major tributaries before it eventually joined the Euphrates.

164. The floods in Iraq were very important and any policy for the development of irrigation in the country had to take flood control very much into consideration. In winter and early spring there were sudden floods, more particularly on the Tigris, and they had very seriously threatened Baghdad, particularly during 1953–54, and on a number of occasions in the past had destroyed Baghdad, so that it had been essential to take floods into account. The irrigation investigations had been done on monthly figures with the help of an IBM 650 computer. During the flood season, in the winter and spring, certain maximum end-month contents of reservoirs had been specified to which the analysis had to conform, which had meant that the reservoirs were definitely lower during the flood season than would otherwise have been the case. They had been somewhat arbitrarily fixed, and the intention was that as more data from the streamflow forecasting service, based on precipitation and snow surveys, were obtained and more experience gained they would be modified and perfected. That was something which had had to be imposed on the irrigation studies, which were done monthly with the computer. The floods themselves had been done by hand because they lasted only for a few days and it had been found simpler to do them by hand.

165. Discharge limits had also to be considered. For instance, the maximum discharges would be limited by the outlets from the reservoir or by the spillway and in some cases by the river channel itself. They gave maxima. Minimum values were usually on account of irrigation and water supply, and in some studies on account of hydro-electric power and navigation.

166. The systems studied included five major reservoirs on the Upper Tigris and tributaries, one barrage and flood diversion scheme in the Tigris, two offstream reservoirs, one of which was the Wadi Tharlthar depression, and linking canals had also to be considered between the four tributaries to obtain the optimum distribution of water

for irrigation. They had been fortunate in having the help of Mr Allan on these studies throughout, and it would be interesting to have his impression of them as compared with the Nile studies. Mr Binnie's impression was that, owing to the greater number of criteria and the more numerous maximum and minimum limits of reservoir contents and discharges, the Tigris study had been a good deal more complex than that of the Nile. But for the wonderful work which the Authors had done and their research into the subject, the Tigris studies, on the scale and with the scope which had been adopted, would have been impossible. With electronic computers and the Authors' flow diagram system, it had been possible to extend the scope of the studies enormously, and on the whole the results had been very successful, which they would not otherwise have been. They had been based only on the records of 27 years, and that was their weakness, but at least the information available had been sufficient, he thought, to assess from the hydrological aspect the comparative benefits of the various alternative schemes which had been investigated.

Dr M. P. Barnett (Massachusetts Institute of Technology, Departments of Physics and Electrical Engineering) said that the work reported in the Paper would be regarded in the future as a classic study in computer simulation. It provided also an admirable survey of a realistic system to which modern methods of econometric analysis might be applied. A number of comments might be made that related this work to allied and to wider fields of activity.

168. Considerable emphasis was placed in the United States on the use of the computer to simulate systems such as rivers, vehicular traffic networks, manufacturing plant, and so forth. Structures (such as dams, traffic lights, factory layout) could be planned for all of these systems that permitted partial human control to be exerted over the general behaviour when subject to external influences (such as rainfall, traffic arrivals, market requirements) that were to some extent random. In general, a design must be found for such a structure and a policy developed for its operation, that optimized the behaviour of the system by reference to some suitable criteria (that related to, say, loss of water by evaporation, mean transit time of a vehicle through a congested traffic zone, mean production delay time). Mr Brian Meek and Miss Dorothy Emery deserved particular commendation for their success in processing, on a relatively small computer, numerous variants of a simulation as complicated as the Nile model. Comparable studies that indicated the varied use of simulation included the work on the U.S. social economy with which Dr Martin Greenberger of M.I.T. was associated, and the simulation of traffic flow at road junctions started at the University of Michigan by Dr Harry Goode.

169. The ease of processing a simulation study was determined to a large extent by the power of the languages that could be used by the engineers and administrators to formulate their thoughts concerning the system to be simulated, and in which their communications with the computer and between each other could be expressed. The conventional written languages of human society provided a powerful medium for the concise description of complicated situations and procedures (though if the systems and sentences were very complicated, internal inconsistencies might be obscured). Conventional English, however, was still remote from the form of instruction that the computer could obey. Arithmetical operations usually were performed by the computer by reference to instructions of a very simple nature (for example that would add or multiply two numbers together) that could be decoded directly by the computers internal circuits. It was a very tedious process for a human to prepare a representation in this "machine language" of, say, the Nile simulation, though it had been necessary in early 1956 to code NVP I in this fashion. The tedium of programming for most computers had been reduced to some extent during the past 3 or 4 years by the availability of assembly programmes that enabled the computers to translate into their respective machine languages representations of problems in so-called symbolic languages that required much the same measure of detail as the machine language, but which enabled

the programmer to use readily memorized mnemonics in place of numbers in the individual instructions.

170. An assembly programme had made it possible to code NVP II in about an eighth of the time needed for NVP I. Even the symbolic programme, however, was far from intelligible to the non-initiate and, as explained in the Paper, the pictorial language of flow diagrams had provided the medium that the engineer used in the development of NVP II, III, and IV to communicate with himself, with fellow engineers and with the personnel who had created the actual programmes that were fed to the computer.

171. A recent development of considerable importance to the coding of simulation problems was the advent of so-called automatic coding systems (such as the autocode system of Dr R. A. Brooker at Manchester University for the Mercury computer, and the alpha code system for the deuce). These provided programmes that could translate, into machine language, representations of computing problems that were relatively concise and which could at least be understood, if not written, by any engineer prepared to spend a couple of hours in learning the appropriate conventions. The construction of a programme in one such language to simulate the river system considered by the Harvard Water Resources Seminar was discussed in a report by Dr Barnett, in which the description of the system was presented first in concise form, using the full flexibilities of conventional English, then in the form of a sequence of very simple English sentences, that involved no mathematics, then as a sequence of simple English sentences and algebraic equations, and then as a Fortran source programme. The preparation of the third description from the second was very simple, involving just the replacement of words by symbols, and the preparation of the fourth description from the third again required little effort involving, to a large extent, transliteration of equations into a simplified typography. The possibility was being investigated of pushing back the stage at which the computer could accept the problem description, from the fourth of the successive versions just mentioned to the third or second, or perhaps within a year or two, to the first. The problems involved in the direct processing by the computer of descriptions of simulation studies presented in relatively free English centred on questions of linguistics that were under intensive investigation already in connexion with machine translation between conventional languages. For the encoding of such descriptions to be rapid, machines of a type radically different from those now in use would be needed, probably in which streams of information could be matched at many points in the computer simultaneously. Programmes had now been developed at the Los Alamos Scientific Laboratories of the Atomic Energy Commission, that made it possible for the computer to create a working programme if it was provided with an algebraic description of the flow diagram, and it would be interesting to apply this technique to some simulation problems.

172. The mechanics by which the communication back and forth between engineer and computer could be effected had a profound effect on the speed with which ideas could evolve, concerning the design of the system being simulated. An activity such as the Nile Valley Plan was dominated by the need for repeated changes in the details of the simulation model. Its gross structure could be altered by the introduction or elimination of particular reservoirs, numerical details could be varied, and mathematical relations (such as control equations) changed. Although it was possible at times to anticipate a number of variants and to provide for their automatic processing, it was of considerable advantage very often if the engineer could supervise the processing of successive runs, using the results of one run as a basis for deciding the specifications of the next. This method of operation required some mechanism whereby changes of the types just mentioned could be communicated readily to the computer, and also required some means whereby the result of successive runs could be presented to the engineer in a form that could be assimilated rapidly as a basis for decision. In the case of the Nile Valley studies, it had been possible to use switches on the computer to set elaborate selections of alternatives, concerning various aspects of the simulation. A single number could be set similarly by means of the switches, or several numbers supplied on cards

that could be punched by hand on an auxiliary machine. Concise numerical results that summarized the behaviour of individual runs had been printed by the computer as soon as they were calculated. It was possible with other equipment to key numerical data, and even equations, into the computer directly on a keyboard much like that of a typewriter, and experiments were being made by Dr Barnett that permitted the processing of revised control equations, and summarizing functions of the results, presented to the computer in this fashion. Results could also be displayed by some computers as graphs or contour plots on a cathode ray screen.

173. With regard to the applicability of computer techniques to other hydrological system, several projects were in progress already or were completed. Simulation studies were being made, for example, by Mr Loren Shomaker of the U.S. Corps of Engineers, and by members of the Harvard Water Resources project (that included Professor Arthur Maass, Mr Maynard Hufschmidt, Professor Harold Thomas, and others). These resembled the Nile Valley work in that no attempt was made to solve the equations of hydrodynamics to determine details of local behaviour in particular circumstances. It may be mentioned that flood routing, lags that switched from one value during normal periods to another value during flood, and fairly elaborate economic analyses of the results were included in the Harvard simulation. Hydrodynamics was at the basis of other studies, such as Professor Stoker's calculations of flooding on the Ohio River, and work developing in the Netherlands that dealt with flooding by the North Sea.

174. The statistical implications of this type of study required further investigation. Of vital importance was some insight into the statistical structure of meteorological phenomena—future workers with more data at their disposal, and perhaps with results obtained from branches now developing of theoretical geophysics and earth science should be less uncertain about these issues. Random fluctuations superimposed on cyclic behaviour were not the only pattern of partly random events that might be operative. For example, stones of weights that were random (but which possessed some probability distribution) dropped at intervals in time that were random (but which also possessed some probability distribution) into a pond would produce disturbances in the water that could be accommodated by a drainage system for which the optimum operating policy could well depend on the probability distributions of weights and intervals, and on cross and auto correlations between these, and which were different from the policies appropriate to a cyclic pattern of behaviour. Moreover, efforts at fitting a pattern of random events of the type just described by fluctuations about a cycle could be very misleading. Experiments were planned by Dr. Barnett that would investigate the dependence of conclusions, concerning the relative merits of alternative systems of control, on the statistical structure of the hydrological data. In view of the present uncertainty about the statistical structure of weather, it would be encouraging if conclusions based on the use of one set of data were insensitive to the precise structure of these data.

175. Modern techniques of econometrics and economic analysis that had an important bearing on problems of river basin development and which were being considered by members of the Harvard project included linear and quasi-linear programming (Professor Robert Dorfmann), stochastic theory (Professor Harold Thomas), and the theory of the discount rate (Professor Otto Eckstein).

176. Although Dr Barnett was an enthusiastic advocate of digital computer simulation, one or two excellent studies in the simulation of economic systems had been made by analogue techniques (for example the work of Dr Holland at the M.I.T. School of International Relations).

Mr A. N. M. Robertson (Sir William Halcrow and Partners, Consulting Engineers) referred to the opinions of Colonel Rawson[8] regarding the regular cyclic periods of changes in the annual discharges of the Nile. When describing the effects of movements of the southern belt of high barometric pressure, which Rawson had considered to have a series of cyclic movements of 19 years' period, moving northward and southward of its central position in latitude 29°S., he had disclosed that the mean values of the Nile

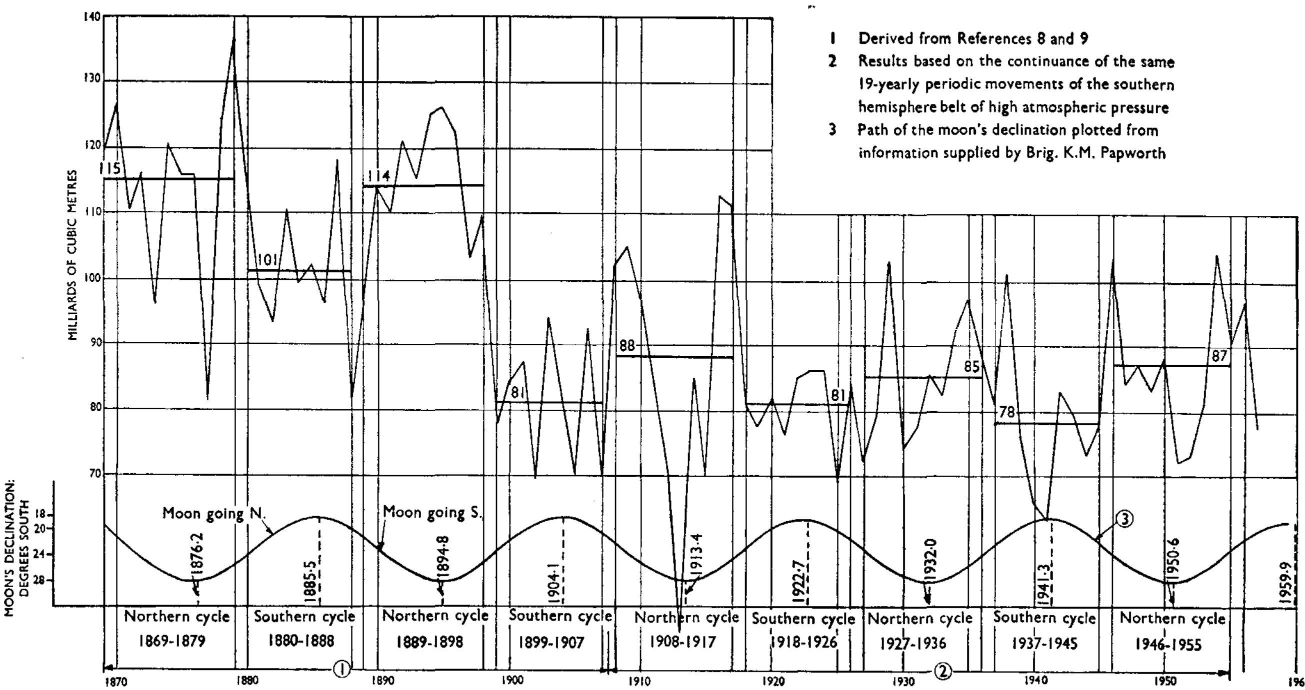

FIG. 20.—THE NILE DOWNSTREAM OF ASWAN SHOWING CYCLIC PERIODS OF DISCHARGE

annual discharge during such periods varied in accordance with the movements of the southern high-pressure belt. (During the northerly half-period the means of the discharges were greater than those during the southerly half-periods. He had subdivided each cycle into 10 years and 9 years, since it was impracticable to involve a half season's flood discharge in the examination.)

178. Rawson's statement had been reviewed and recorded on p. 17 of reference 9.

179. Fig. 20 showed information presented in reference 10, with the addition of the mean average discharges for the 10-year and 9-year "half" cycles. The results of Rawson's review of the discharges from 1869 to the early 1900s are shown at the left of Fig. 20. During the northerly periods the mean values of the discharges had been 115 and 114 milliards of cubic metres, while during the southerly periods they had been 101 and 81 milliards. Rawson had not claimed, however, that those cycles of discharge were the direct result of the movements of the belt of high pressure.

180. Bringing the information up to date by continuing a similar series of 9- and 10-year cycles up to 1955, Fig. 20 showed that the variations persisted, with a smaller but more constant range of difference. Individual opinions could differ regarding the extent to which those results represented evidence of the occurrence of a continuous cyclic change in the annual discharges of the Nile.

181. Since the main sources of the Nile discharge were the Blue Nile and its sister streams from Ethiopia, it was clear that their discharges would also have to be examined. Records had not been kept before 1900, but since then there was evidence of definite cyclical changes of the means of the annual values during the 9- and 10-year periods used by Rawson (see Fig. 21) for the Blue Nile at Roseires.

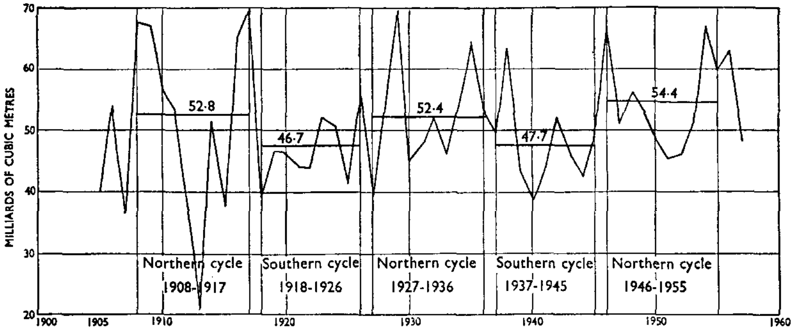

FIG. 21.—THE BLUE NILE AT ROSEIRES SHOWING CYCLIC PERIODS OF DISCHARGE

182. Fig. 22 referred to Lake Tana inflow, and Figs 23 and 24 to the Atbara and Baro Rivers. The same sort of cyclic changes and variations were clearly to be seen.

183. Although rainfall records were scanty in Ethiopia, there was a record for 37 years at Addis Ababa. The figures were given in vol. VI of reference 1, and further information supplied by the Ethiopian Embassy brought the record up to 1957. Again the cyclic variation was manifest. During the northerly periods the mean values of the annual rainfall were 1,329, 1,222, and 1,200 mm, compared with 1,154 and 1,060 during the southerly cycles. But since the records were confined to a single gauging point no general conclusions could be drawn.

184. Returning to the discharge record of the main Nile downstream of Aswan, an interesting coincidence could be seen in the lower part of Fig. 20, which represented the periodical changes in the declination of the moon. Russell[11] had considered that there was a 19-yearly period in changes of rainfall in certain districts of Australia which had a relation with a 19-yearly period of change in the declination of the moon. Mr Robertson showed a graph to illustrate this in the nineteenth century.

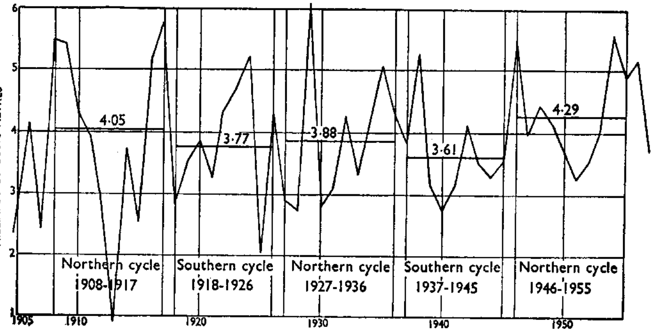

FIG. 22.—LAKE TANA—SOURCE OF THE BLUE NILE SHOWING CYCLIC PERIODS OF INFLOW

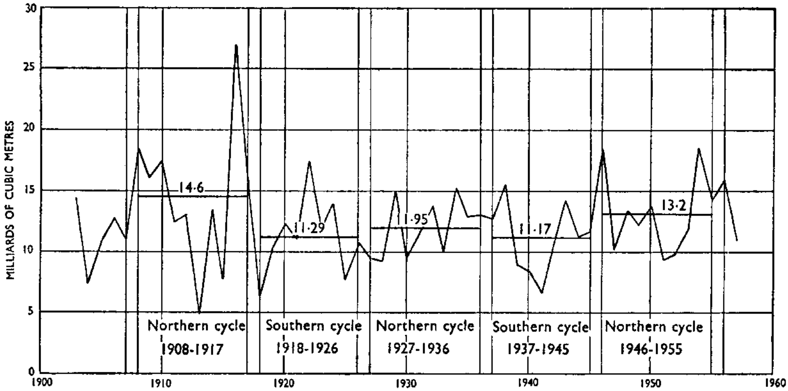

FIG. 23.—THE RIVER ATBARA AT ITS MOUTH SHOWING CYCLIC PERIODS OF DISCHARGE

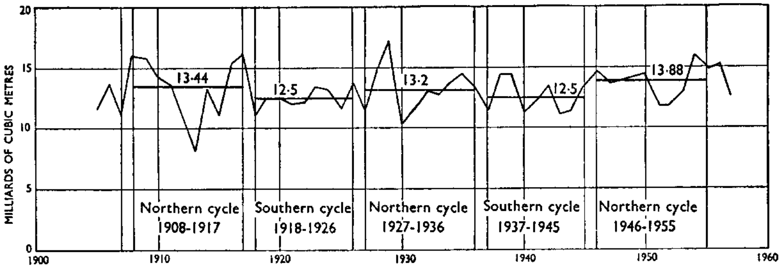

FIG. 24.—THE RIVER BARO AT GAMBELLA SHOWING CYCLIC PERIODS OF DISCHARGE

185. On extending the graph into the twentieth century, as shown in Fig. 20, and comparing it with the Nile discharges, there seemed to be some association between them, but a reference to the Meteorological Department had shown that this was not so. The graph had been prepared by Brigadier K. M. Papworth, R.E., who was at present associated with work at Armagh Observatory in Northern Ireland. He reviewed Mr Russell's graph and considered it needed but little change to represent it as being the record of the Moon's course in the 18·6 year period known as the Saros cycle. The record was thoroughly up to date, but Brigadier Papworth also considered that the changes of the Moon's declination would not affect weather to a degree which would influence the Ethiopian rainfall.

186. So the origin and course of the periodic changes in the Nile discharges was still unknown and at present must be a matter for speculation, or was it a coincidence?

Mr Herbert Addison (Consultant), who remarked that when one heard of an astonishing piece of electronic apparatus there was often a temptation to try to catch the machine out, said that at least it was interesting to compare the information given in the present absorbing Paper with information from other sources. One could select, for example, Fig. 18, which showed the estimated contents of the Semna and Aswan reservoirs during the period 1905–52, and compare it with the almost identical diagram which had been published in an official Egyptian report on the High Dam Project dated 1955; this embraced the period 1870–1954, and was intended to show how an enlarged reservoir would have operated had it been in existence during that period. Presumably that diagram had been based wholly on human mathematical computations. A preliminary inspection showed remarkable similarity between the general shapes of the two curves. Both the Authors' electronic one and the Egyptian conventional one showed a very full reservoir about the year 1911, and a very empty one about the year 1915. The lean years of 1940–45 were well represented in both diagrams. Only one apparent discrepancy could be noticed: whereas the electronic curve dropped to its absolute minimum about the year 1942, the Egyptian curve suggested that at that period there was still quite a comfortable margin of water in the reservoir. Bearing in mind, however, that the diagrams had been based on different sets of assumptions, the comparison gave confidence in the Authors' procedure.

188. It might be asked, therefore, whether or not the procedure would gain the confidence of the engineers responsible for the control works on which the entire plan depended. Those engineers might be stationed anywhere in a region extending over 30° of latitude, and they required day-to-day instructions about the manipulation of the sluices or outlets under their charge. Would they accept the instructions issued by the electronic computer?

189. As for the instructions fed into the computer, these would be much more complex than those issued by the Authors. The Authors had apparently assumed that all the control works were in operation from the start of the programme, whereas to simulate the real conditions in the Nile Valley the changes year by year had to be taken into account—how much new land was put under irrigation each year, which new reservoirs were put into operation, how the necessary reserve of water was gradually accumulated in the Aswan Reservoir itself, and so on. Moreover, the electronic computer in future years would have no foreknowledge of the future behaviour of the Nile. The Authors might say that their computer had not been allowed to know what had been happening in succeeding years, but the Authors and their colleagues had known, and it implied no disrespect to imagine that that knowledge might have influenced their handling of the computer input. If the Authors felt confident that their methods took account of those new complexities which would arise in the future, the value of their Paper would be even more evident.

Mr P. A. Scott (Partner, Sir William Halcrow and Partners, Consulting Engineers) said that Mr Allan, in his introductory remarks, had appealed for a method of evaluating data of future input to the reservoirs, and Mr Robertson had touched on this in relation to the probability of the input varying in cyclic periods of 10 and 9 years. When considering the regulation of the future system the input to the reservoir was even more important than the records of the past. So far, no one had produced a formula for forecasting this, but many people were doing a good deal of work on this subject, and his own firm, in their own small way, had had a problem in Central Africa where they thought that they could claim to have had some qualitative, and a certain amount of quantitative, success in forecasting the water levels of Lake Nyasa. It would be interesting to know whether or not the Authors thought that by similar methods it should be possible to forecast with some chance of success the future flow from the various tributaries of the Nile. The system was not black magic, as most people seemed to think, but was really an application of studies of past records to the probability of future behaviour.

191. The Authors had been extremely skilful in predigesting the information which they had to feed to their computer so that it had been able to accept the information and give them the answers. An expert on the subject had spoken about it in the discussion. Although many engineers could quote other problems which the digital computer had solved, there were some which it could not solve. He mentioned a case where an answer had not been obtained, and he would like to know whether or not there was a method of doing it. It concerned the computation of variable flows in a network of drainage channels. They were discharging by gravity at low tide and acting as storage for a constant run-off when the sluices were shut against the tide. The system never settled down to the uniform flow conditions, and, starting from a trial condition near the sluice, it was necessary to work step by step upstream to find approximate conditions in each half-hour or hour of the complete tidal cycle. Each step upstream was a trial-and-error balance involving the Manning formula. Each time period calculation must be repeated until the sluice condition balanced the weir discharge formula, and the whole cycle must be repeated to find equilibrium for a given trial set of drain dimensions. It was a long and laborious business and seemed a suitable job for a computer. In fact, however, it had been found that the frequent occurrence of the $\frac{4}{3}$ power in the Manning formula for water surface slope and the $\frac{3}{2}$ power in the weir formula, along with the very large number of different formulae and constants in the separate steps, led to the machine programme being so lengthy and involved, as to be worse than calculating the problem oneself. An analogue computer might be more helpful, but he understood that the cost of setting up one for these problems would probably be prohibitive. There still seemed to be, therefore, some problems in hydrology and hydraulics which the computer could not necessarily solve.

The following contributions were received in writing.

Mr N. J. Cochrane (Sir William Halcrow & Partners) commented on the use of a digital computer which, he said, had successfully overcome a formidable and necessary amount of computation. However, while it simplified the analysis of historic or hypothetical situations the machine did not, apparently, include a predictor segment. There were sophisticated predictors available nowadays for investigating many scientific problems; for example, to determine the probable tracks of missiles given a few points on their paths. In all cases the predictor had to compare the evidence presented to it with families of standard paths and select the most probable. The more data, the more certain the prediction. The dilemma was how and when to act. If soon, the counter action might be wrong because the early prediction was inaccurate. If too late, the counter action might be without value, although it would have resulted from an entirely accurate conclusion. The analogy with hydrological problems seemed to him to be close and there was evidence to support such an approach in the case of the Nile.

193. He said that Mr Robertson had referred to the unmistakable continuation of what might be called the "Rawson" 19-year cycle in the long-term behaviour of the Nile and its tributaries. Mr Cochrane was interested in shorter-term variations and had drawn

attention to some of them[12–15]. In the present instance his work on the Lake Victoria/Nile complex was relevant, and he had since added appreciations of the hydrology of Lake Tana, Atbara, Baro, and Blue Nile at Roseires. They were all shown in Fig. 25, where a similar short-term irregular cyclical mode of behaviour in all could be observed. There was in fact a distinctive qualitative relation with the turbulence or "rate of change" of sunspots. There were also anomalies.

194. Mr Cochrane did not attempt to describe the mechanism of that relation, nor had he been able to evolve a plausible statistical treatment. The data were not "events" but averages in sequence and this appeared to invalidate all the commonly-used statistical correlations. Nevertheless, the relation existed and, using a rather primitive method, he had had some success in predicting the trend and even the magnitude of the water balance in the Lake Nyasa/River Shire complex for three successive years[16]. He hoped that a similar approach, including Rawson's effect, might ease the practical management and control of the Nile and its tributaries by predicting the trend of its future hydrology.

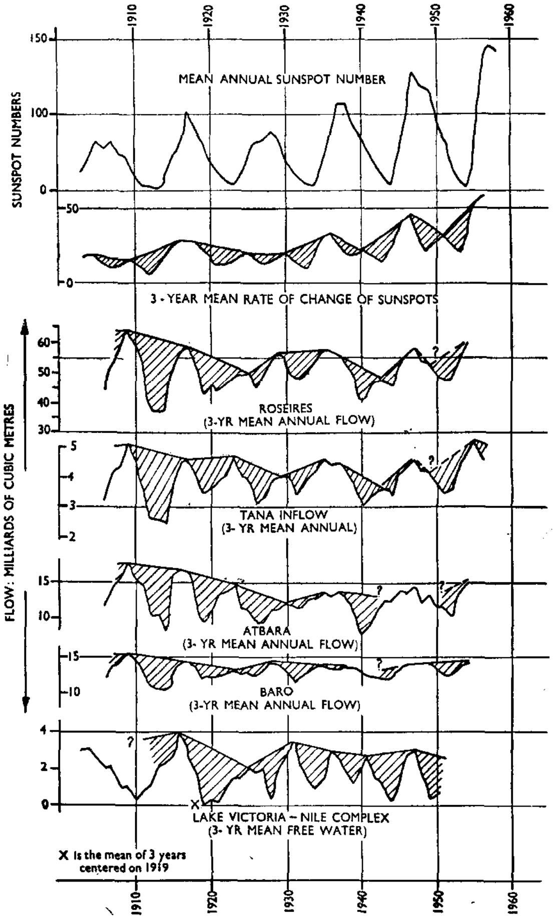

FIG. 25.—HYDROLOGY OF TRIBUTARIES OF THE NILE

Mr R. P. Black (Scientific Consultant to the Ministry of Public Works, Egypt) congratulated the Authors on introducing the electronic computer to help solve the problem of the Nile, namely, "how to make the largest possible volume of water available for use by the riparian states of the Valley, and keep it as nearly uniform as may be from year to year".

196. The Authors had made use of the available data of the period of 48 years (1905–52), in which the average annual flow of the Nile, measured at Aswan, was 83 milliard m^3. They had found quite an elegant regulation, which would make some 80 milliard m^3 available for irrigation each year with an overall variation of about 10%, while greatly increasing the firm hydro-electric power throughout the basin. By omitting the power reservoirs in the Sudan, and transferring the Semna storage to Aswan, they had pointed out that an additional 4 milliard would on the average be available, and the evaporation losses due to storage reduced to 8 milliard m^3/year. The benefits to be derived from the Upper Nile storage were estimated at about 9½ milliard m^3/year. The capacity required at Aswan for 84 milliard/year was 117 milliard m^3.

197. Considering Aswan as the only overyear storage reservoir, then listing (for the same period, 1905–52) the departures from the average of individual years and forming the accumulated sum of those departures, it would be found that the range was 76 milliard m^3. Starting with a capacity of 35 milliard m^3 would give the range as 10–86 milliard m^3, which, after allowing (as the Authors did) 30 milliard m^3 of dead storage, would become 40–116 milliard m^3, with a mean capacity of 78 milliard m^3. Further, the reservoir content would be below the mean for 24 years and above it for the same time. The mean loss would therefore be on a content of 78 milliard m^3, which, according to the Authors' own figures, was 8 milliard m^3. Thus, 75 milliard with an overall variation of 10% would be available each year. Adding the benefits to be obtained from the Upper Nile projects, led again to the Authors' figures of 84 milliard m^3, apparently without the use of virtual storage and without either Lake Tana or the Upper Blue Nile reservoir. The small capacity required to equalize the flow of that period at Aswan, actually less than an average year's flow, suggested that there was something remarkable about that period; and in fact there was.

198. Each of those years was a "could be" future year, and as there were 48! possible arrangements of those 48 years, there were that number of possible future 48-year periods. Many of the arrangements would produce practically the same result, but there would remain a sizable number (enough to keep even an electronic computer busy for a long time) which would produce quite different results, and Mr Black was surprised that the Authors, when they had an electronic computer at their disposal, had not "shuffled the cards".

199. *He referred to two extreme cases:—*

(1) The years arranged in order of magnitude:
    (*a*) starting with the highest,
    (*b*) starting with the lowest.
(2) The years arranged, highest followed by lowest, then 2nd highest followed by 2nd lowest, and so on.

In No. 1 the range of accumulated departures from the average was 234 milliard m^3:—

(*a*) No starting storage was required to keep the reservoir from emptying, and it would operate entirely in the upper half of its range.
(*b*) 117 milliard m^3 of starting storage would be required, and the reservoir would operate entirely in the lower half of its range.

In No. 2 the range would be 58 milliard m^3, and 21 milliard m^3 for starting storage would be required.

200. The two extreme cases illustrated the fact that in any series of years, the order in which the years occurred was of great importance in determining both the total storage that would be required to produce the average each year, and the starting storage to prevent the reservoir from running dry; although both the average and the standard deviation remained fixed.

201. There would be no great error in taking the mean value of the storage required (for all possible arrangements of those 48 years) as about 146 milliard m^3. Thus, the storage required for the actual series of years (1905–52) was much nearer to the minimum than it was to the mean of all possible arrangements, and far removed from the maximum.

202. Applying the same analysis to the reservoirs at Victoria and Albert lakes gave the results shown in Table 14.

TABLE 14.—STORAGE REQUIRED TO PRODUCE THE MEAN INFLOW EACH YEAR

	Milliard m^3		
	For the years as they actually occurred	For the most favourable arrangement	For the least favourable arrangement
Lake Victoria	100	81	400
Lake Albert (excluding Victoria Nile)	50	17	68

203. If Lake Albert was used to balance the torrents between the lake and Mongalla as well, then for the actual period (1905–52) the storage would rise to 65 milliard m^3. Victoria, therefore, was like Aswan, in that the storage required to produce the average each year in the period (1905–52), was nearer to the minimum of all possible arrangements of those years than to the mean, whereas Albert differed, in that the storage was somewhat greater than the mean.

204. Even with the 200 milliard m^3 of storage now available, it seemed that Lake Victoria must spill sometime or other, especially if attempts were made, at the Owen Falls Dam, to hold the rise of the lake, when the storage exceeded some lesser figure. If spilling did take place, it would have either to be held in Albert, or passed on to the Sudan. Some capacity in Albert had, therefore, to be allotted to the flood protection of the developed sudd region.

205. In the Authors' regulation, part of the storage required to equalize the inflow into Lake Kioga was held in Lake Albert, so that if provision had also to be made for flood protection, the 100 milliard m^3 of storage left little room for virtual storage.

206. The Authors' plan included an 18-milliard-capacity reservoir in the Blue Nile canyon. During the Italian occupation of Ethiopia, Pontecorvo had estimated that he might get 5·5 milliard m^3 storage by raising the water level 30 m at each of the several places, where the slope appeared to be favourable, and much less than the overall average of 150 cm/km. The longitudinal section he had used was that given by Cheesman[17]. It had depended entirely on aneroid readings, and was liable to serious errors. Perhaps the Authors had some more recent information, but to Mr Black the possibility of an 18-milliard-m^3 reservoir anywhere in the canyon did not look promising. Above Roseires there was a discontinuity in the slope of the Blue Nile, 150 cm/km above and 12 cm/km below, shown clearly by the change in the bed from pebbles to pure sand. The only observations of silt load had been made below Roseires, and the load in the canyon could be many times greater, which did not bode well for overyear storage. The late Walter Grabham's geological section across Ethiopia had shown that the river had cut its way right down to the sandstone.

207. The Authors' Lake Tana project had been first suggested by Dupuis, 56 years ago. At the time, he had thought the lake water might be drawn off by a tunnel into the upper reaches of the Dinder, but he had regarded the project as impracticable, partly because the water would reach the Blue Nile below Sennar. Mr Black's discovery, in 1921, of the location of the upper reaches of the Balas, close to the escarpment, had given the project a new lease of life, but the Authors' requirements that the Balas should carry 75 million m^3/day from the lake seemed to be far beyond its capacity.

208. One had only to journey through the western lowlands of Ethiopia, from the escarpment to the Sudan frontier, to realize that if the waters of Lake Tana were all discharged *via* the Balas, the "ultimate" benefit to the Sudan and Egypt might be the complete loss of the whole lake discharge.

Mr H. F. Wilmot (Sir Alexander Gibb & Partners) remarked that the Paper had given the fullest statement to date of the problems involved, with all their ramifications. The results obtained, however, depended wholly on the judicious feeding of the electronic computer. One important result achieved was that establishing the limitation of the storage levels in Lake Victoria, based on the past records 1905–52.

210. In order not to be lulled into a feeling of false security, that result had to be qualified by the two conditions:—

(1) that the system of control downstream at Kioga had first to be implemented; and
(2) that no significant departure from the records of the past 56 years should occur.

The statistical chance of 1/500 for a maximum 6 months' discharge of at least 160 M/M occurring was always possible. That period of the heavy rainy season was more critical than that over the whole meteorological year, and compared with the 195 M/M shown in Fig. 17 which occurred (over the whole year) in 1942. However, a very real mitigating factor existed now in that eight turbines out of the final ten had been installed at Owen Falls, which would have a great effect in reducing the variation in levels of the lake.

211. Regarding § 44 the restriction of the split $X:Y$ of the waters as between Egypt and the Sudan between 2:1 and 3·5:1 had, with the recent agreement, vindicated the first assumption. Assuming Y as the actual value of water used in the Sudan, and therefore adopting its Aswan value as $\frac{1}{1{\cdot}094}\,Y$ or $0{\cdot}914\ Y$, would provide a more exact "paper" solution than that given, i.e. if it were possible to assess actual figures so accurately; it would at any rate avoid the possible criticism of the Sudan exceeding its agreed share by 9·4%.

212. The results obtained must make it possible to give some indication of the priority with which the many works outlined should be achieved, and the opinion of the Authors would be valued from the two-fold aspect of the interests of Egypt and the Sudan. For the former, Mr Wilmot had long since considered the Jonglei Canal as giving the quickest immediate return, but it left its special problems for the Sudan itself. The already planned Roseires Dam was obviously the first choice for the Sudan.

213. The Paper left a hiatus in the chain of reasoning where the *deus ex machina* or electronic computer was appealed to for the final result in § 84. Mr Wilmot understood that the function of the I.B.M. computer used was the solution of linear equations. The fundamental notation of so many possible variables as adopted had been skilfully achieved, but immediately created a real difficulty of ready comprehension due to its complete departure, of necessity, from the usual variables used and the variable parameters. It was clear that the number of solutions possible from the fourteen equations given in the Paper was infinite, and from them a maximum of fourteen unknowns could be computed only if given values were assigned to all the other unknowns which appeared.

214. There were three main conditions to be fulfilled in conducting that investigation:—

(*a*) that the availability of water did not flout the probability of supply as indicated from past records;
(*b*) that the ratio of $X:Y$ was assigned (reducing the variables by 1); and
(*c*) that $X+Y$ should be a maximum (with due regard to the modifying factor of evaporation).

It was clear that (*a*) was strictly limited by the length of those records, and such calculations as were made (based on those) must be accepted with that qualification. Short records could give misleading results leading to uneconomic developments of varying magnitude; in the case of the Nile the amount of error involved should be relatively small.

215. Before reliance could be placed on results given in any method of calculation, whether those derived from the results of, say, hydraulic models or from machinery, it was surely advisable to try them out (as was invariably done in the case of the former), to see whether they reproduced conditions or answers which conformed to actual conditions. Had this been done in the present case, and could complete reliance be placed on the results achieved?

216. The method of successive feeding-in of the information, whether year by year for long-term storage, or month by month for yearly discharges, must be an extremely tentative process, and presumably the columns of successive figures capable of being reproduced were limited—in this case to fourteen—by a control mechanism on the machine. Should the card-feed system get displaced in any way, either by human error, or a slip in the mechanical feed itself (two cards stuck together, etc.), the whole result would be invalidated.

217. The implication would seem to be that the judgement and experience of the manipulators of the feed cards to the computer were the major factors in the carrying out of those calculations, and achieving results which were at all worth while.

Mr H. W. Underhill (Head of Soil and Water Resources Division, Administration of Tripolitania) said that few other rivers would offer to its planners the same advantages as the Nile, particularly the large natural storage and many suitable sites, well distributed throughout the system, for large artificial storage. How many river planners could assume a ratio of reservoir capacity to mean annual flow of almost 5:1? (the sum of the reservoir capacities in § 92 being 402 milliard m³ and the mean annual flow given in § 91 as 84 milliard m³). In the recent Tigris studies that ratio was more like 1:1, and the potential reservoirs were less conveniently situated for irrigation development. It was

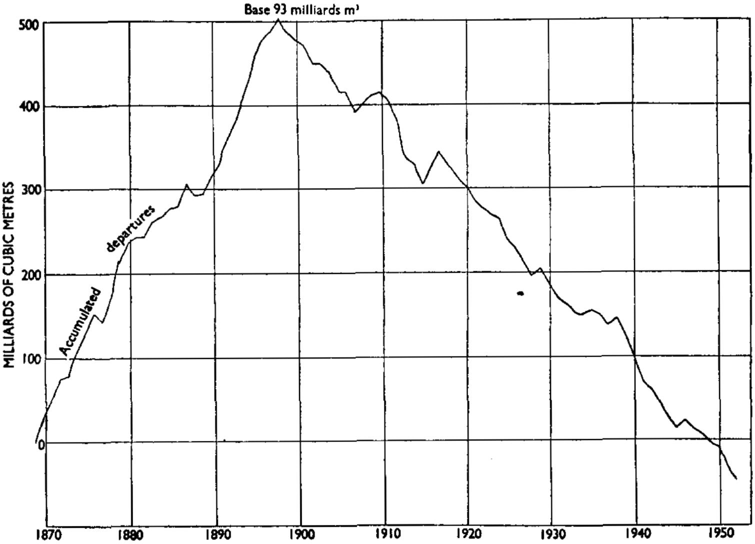

FIG. 26

significant that run-off forecasting was not mentioned in the Paper. There was little need for it on the Nile.

219. A study of the past was the only basis on which developments of that kind could be planned, and the Authors had taken "the longest period for which full hydrological data could be provided". Although full data went back only to 1905 the Nile was unique, in that records of some kind went back one or two thousand years. Why, in their planning for the "ultimate" development of the Nile Valley, did the Authors make no mention of those records? Mr Underhill had no access to the basic Nile data, but Fig. 26, which was extracted from Fig. 5 of Dr Hurst's 1956 Paper[7], showed that the Authors' period was one of no major variation in discharge, such as was immediately apparent in the period 1868–1952. Was the Authors' analysis undertaken to demonstrate the maximum possible $X+Y$ for the period of analysis, or to plan a control and regulation system for the future? Had they made any probability studies of possible future variations in discharge pattern, or considered the suitability of the control and regulation system described in the Paper to such changing conditions as had occurred in the past and were likely in the future?

220. In Table 11 the Authors had given abstractions for irrigation (as at Aswan) available to the Sudan and Egypt. Were those figures truly comparable? Presumably the Sudan could use all her quota for irrigation, but would not Egypt require some flow to the sea for navigation and pollution control? If so, would the Authors estimate that requirement?

Mr John Bolton (Partner, Bolton, Hennessey & Partners) said that although the new technique, so well described by the Authors, was very welcome, the merits of the Nile Plan which they had propounded were open to serious criticism. The several references in the Paper to Ethiopia—its contribution of over 80% of the present annual Nile flow below Atbara; the many undoubted possibilities of major storage projects; the proposed drawdown of Lake Tana during its use as a storage reservoir (with no regard to lakeside development or amenity); and the lugubrious question marks against Ethiopia's requirements for irrigation water (Table 11)—all those added up to what must have been an indictment of their Nile Plan.

222. For various reasons Ethiopia had been unable, so far, to submit her case for upstream riparian rights and needs. That case was now under preparation and would quite definitely make necessary major alterations to the Nile Plan proposed by the Authors. And that, in spite of the November 1959 agreement on Nile Waters signed between Egypt and the Sudan, an agreement which also ignored Ethiopia's needs.

223. Ethiopia had a population of 20 millions, which was expected to double in less than 50 years; she was dependent economically almost entirely on agricultural production, and needed the use of her Nile waters for irrigation and power. Her claim for irrigation, when lodged, may well be in the region of 16 milliard m^3, and there was not much doubt that it could be substantiated even on data presently available. The time was fast approaching when all countries forming part of the Nile Basin must get together to evolve a mutually satisfactory development plan and an acceptable share-out of resources. Any unilateral action or any "treaty" which ignored the right of others was dangerous. The livelihoods of increasing millions were at stake and the political dangers inherent in such a situation must be apparent to everyone.

224. It would be clear to those who had studied the Nile problem in any detail that the fact that Victoria's available storage of 200 milliard m^3 could not be fully exploited underlined the need for major storage on the rivers flowing out of Ethiopia.

225. Use of Lake Tana as a 15-milliard reservoir was out of the question, since it would turn the shores of what was almost a national shrine into enormous mud flats for years on end. The storage available there must be written down to a cyclic 2 or 3 milliard m^3, since 1 or 2 milliard m^3 would probably be extracted in the future for irrigation in the Tana area.

226. However, on the Blue Nile, between Tana and the Ethiopian frontier, on the Tekazze (Atbara), and on the Didessa (a major Blue Nile tributary), there were sites for

storage of approximately 150 milliard m^3 if engineering imagination in scale with human needs was used. Storage of the order indicated, if constructed in lieu of Roseires, Sabaloka, Fourth and Fifth Cataract, Semma, and part of High Aswan (Table 11) would reduce evaporation losses by 7 or 8 milliard m^3 p.a., and still provide as much or more power than the projects replaced. It would also greatly assist (once Jebel Aulia was out of the way) in easing the problems of the White Nile flow. In a river basin where annual flow must very soon be cherished to the last milliard, the factor of reduced evaporation losses alone should be a decisive one in planning future projects.

227. There were, in addition, other major factors to consider. The Authors had used the period 1905–52, when Nile flow at Aswan averaged 83·77 milliard m^3/year. In the period 1871–1908 the average annual flow was 103 milliard m^3, and should a similar cycle return there would necessarily be considerable overspill at Aswan. As Dr Hurst had pointed out, wastage on high flow implied maintenance of the hydraulic capacity of the Damietta and Rosetta channels. That was normally achieved by annual flushing but comprehensive control measures upstream could make that impossible for many years. How was that problem to be tackled?

228. That led Mr Bolton to another question. In view of the long-term average flow in excess of the assumed 83·77 milliard m^3/year at Aswan, had the possibility been considered of using Victoria's untapped 80 milliard m^3 as a master balancing reserve, which might increase availability by as much as 10 milliard m^3/year if the additional storage was constructed in Ethiopia?

229. Again, with population increasing in Africa and the increasing usage of Nile waters, the annual balance available for filling the new storage reservoirs would progressively diminish. For example, if the Jonglei Canal should take 10 years to complete, the population increase in Egypt alone, even if the canal were started immediately, would be 4 million, and hardly any of the extra 7·82 milliard m^3 of water would ever become available for overyear reservoir filling.

230. Why had no study apparently been made of the possibilities of conserving and exploiting the considerable flow in the tributaries feeding the Western Swamps in the sudd region?

231. The Authors' assumptions on drawdown (§ 35) were surely impracticable. Sooner or later a new analysis would have to be made, taking into account possible variations in a phased construction programme and progressive annual increase in water requirements resulting from population growth. From such a study would evolve a clearer realization of the magnitude and tempo of the civil engineering programme necessary to meet the demographic crisis.

232. Such a study, too, placing emphasis on the needs of people rather than on economic factors would underline what was undoubtedly the world's major political problem in this second half of the twentieth century. For the Nile Valley problem large though it was, represented only a small fraction of the global effort facing mankind.

233. The Authors had taken a great step forward in their approach to the Nile Waters problem, but they had also had to admit that solutions were not necessarily entirely dependent on mathematical or engineering considerations. In the final analysis, politics and people must have the last say. The time had surely come, concluded Mr Bolton, for a conference of all countries interested in the exploitation of the Nile's potential. Perhaps the calling of such a conference was a proper task for the World Bank with its recent experience of the Indus problem, and its close contact with those who would be required to muster the necessary financial resources. Certainly, the time for short-sighted nationalism in the solution of such problems was long past.

Mr Y. M. Simaika (formerly Under Secretary of State, now Technical Adviser, Ministry of Public Works, Egypt) said that the Authors had made free use of all the work done by numerous previous investigators of the problem, many of whom had now passed from the scene of their labours. The control projects included in the plan, with the exception of a canyon reservoir on the Blue Nile and the High Aswan Dam, had been discussed for many years—some for more than half a century, and some of them seemed less likely of realization today than they did 50 years ago.

235. The publication in 1946 of vol. VII of "The Nile Basin" had, for the first time, placed the problem of overyear storage to meet the menace of low years on a scientific basis; it showed that the Nile was a hydrological unity, in that the benefit from the projects being worked together as a single unit was much greater than the sum of their separate benefits. The combination of the projects to store water in one part of the valley from excesses in another part was termed "virtual storage", and the Authors of the present Paper had claimed to have made the most of it to reduce the losses inseparable from storage on a very large scale.

236. The Authors' division of their regulation into monthly periods was, as they admitted, an unsatisfactory approximation. They had made use of mean losses over the whole 48-year period and "median" lags, the figures for which were derived from "The Nile Basin", but their definition of lag was quite different from lag as used anywhere in "The Nile Basin". In "The Nile Basin" lags were tabulated under the heading "Time of travel of fluctuations along the Nile"; they were, therefore, intervals of time between corresponding states at different stations on the river and lag, as so defined, did at least mean something definite. The Authors' idea of the water at any section on the river all having a Lake Victoria "date ticket" on it was surely fanciful. Further, the operation of virtual storage necessitated the White Nile carrying 170 million m^3/day for several months on end; did the Authors really believe that losses under such conditions could be considered even approximately normal?

237. Referring to § 36, the recycling process for ensuring that the reservoir capacity at the end of a period should be the same as at the beginning could not be used for the future. When planning for the future one had to be guided by the analysis of many phenomena, as suggested by Hurst[7].

238. The question of flood protection was referred to only once in the Authors' plan—3 milliard m^3 storage is provided in the Upper Blue Nile reservoir for the protection of the Shendi reach (Atbara to Sabaloka). What would happen in the densely populated Delta of Egypt, now being rapidly industrialized?

239. The Delta had suffered severely in the past from the effects of high floods, but the damage done then could only be a small fraction of what would be done nowadays if an 1878 flood occurred. In that year, although no warning of a really dangerous flood could be given before September, no less than 80 milliard m^3 reached Aswan in the 3 months August to October.

240. No amount of virtual storage could make the slightest difference to that figure and only considerable storage, immediately available in Aswan reservoir, could avert a major disaster.

241. The Authors' plan had no margin of safety anywhere, so that the results of unavoidable errors or regulation and catastrophes, which must occasionally arise, would be passed on to Egypt. That made the plan unacceptable.

Mr A. E. Griffin (Consultant) asked if a rough indication could be given of the man hours economized by resorting to electronic computation in the preparation of the Paper.

243. Was it fair to claim that the control works mentioned in § 92 would have provided an irrigation benefit of 80 milliard m^3/year, without mentioning that the works already in existence would have provided a benefit of about 52 milliard m^3/year (though possibly not within a variation of 10%), less some figure of benefit involving no control works at all? It would have seemed more realistic to say that the works in § 92 would have provided an additional benefit of about 28 milliard m^3/year.

244. Secondly, in considering the ultimate development, had the Authors in mind the reduction of losses in the Bahr Ghazal and the question of watershed management in the region of the lakes? It was well known that only about 5% of the rainfall on the Nile Basin, down to the outflow of Lake Albert, was lost to the Nile. The area of swamp in Uganda was approximately 12,000 km^2, excluding lake-side swamp, an area well in

excess of that of the Sudd Region. Much of that area was made up of perennial papyrus swamps which, in fact, were very numerous watercourses blocked by papyrus growth. Practically all those swamp lines drained into the lakes or the Victoria Nile.

245. About 14 years ago the Uganda Government had been interested in the question of draining and reclaiming suitable swamps, though there had been concern that such measures, if pursued blindly, might have had a desiccating effect on the climate, and other harmful results. In reporting to the Uganda Government on aspects of swamp reclamation, Mr Griffin had suggested some modest pilot schemes, but he did not know what the present position was. It did seem, however, to be worth investigating the possibility of increasing the run-off if it could be done without any adverse effect on the local environment.

Mr W. N. Allan, in reply, referred to the great loss sustained in the untimely death of Mr Morrice since the presentation of the Paper. Mr Morrice had initiated the idea of using simulation by a digital computer to investigate the Nile, and had taken the leading part in the work.

247. The extensive and varied contributions to the discussion had greatly added to the value of the Paper. The inclusion of a brief summary of previous investigations, as suggested by Mr Lacey, would have been very desirable, but had not been possible for lack of space. Mr Allan, however, wished to add his tribute to the achievements of others in the past, of which the Authors had made full use. The discussion had shown how much still remained to be done. Some day, it was to be hoped, a technical history of Nile development would be written; it would certainly be a fascinating story. Meantime, Mr Allan had prepared a brief list of some publications (see Appendix II) relating to Nile development, to supplement the references already mentioned.

248. It would be convenient to deal with the comments under two main heads, first the use of a digital computer, and second the form and operation of the scheme of Nile development. In formulating the investigation, the Authors and their helpers, in close collaboration with Dr M. P. Barnett and his colleagues, had had to feel their way, preparing the input data and evolving the control equations in ways suited to, though limited by, the characteristics and capacity of the particular digital computer used, the I.B.M. Type 650. With present knowledge, and with a computer of larger capacity and greater speed, no doubt the formulation could have been considerably improved. But Mr Allan had no reason to think that the conclusions reached would have been different.

249. Mr Simaika had criticized the use of monthly regulation periods, of mean values for the coefficients of transmission loss, and of "median" lags, applied by adjusting the dates of inflow figures to a common point. The original inflow data were available in the form of "10-day means", but the use of such short periods as 10 days was not possible within the memory capacity of the computer, and in any case would have trebled the time and cost of each run. The adoption of constant mean values for coefficients of transmission loss was discussed in §§ 22 and 23; since the values adopted were such that over the 48-year period, the overall losses were consistent with the total observed discharges at the various points down to Aswan, any small discrepancies in individual months were not cumulative, and the whole computation was internally consistent. These were the important points in relation to overyear storage. The use of constant values for lags, also an approximation as stated in § 29, did not affect the quantities of water arriving at any particular point, but only, to a slight extent, their times of arrival.

250. With computers of greater capacity, it should even now be quite possible to make programmes which would allow for varying lags and varying transmission losses, involving the question of "valley storage". Dr Barnett, in his very valuable contribution, had described the progress made in the technique of programming for simulation, both during the Nile investigations, and subsequently in other fields. The possibilities of the future were certainly great.

251. In the "flow diagrams" (Figs 3–16), which set out the Nile programme as it was finally evolved, there was nothing mysterious about the various terms. Mr Allan hoped that the use of continuity equations (§§ 52–54), and of the test questions to deal

with imposed limits and "impossible situations" (§§ 45–51), would be quite clear. This left mainly the control equations. These were empirical and severely practical, being the expressions, in mathematical forms, of the methods of regulation which had appeared to the Authors best suited to achieve their objects. The computer did not in this case have to deal with these algebraically as simultaneous equations, but merely evaluated what the various reservoir contents, discharges, losses, usable amounts, etc., would have been, if the river had been regulated in the manner specified. In devising and modifying the control equations, the Authors had primarily had regard to the resulting effects during the 48-year period of record. But they had tried to form the equations so that they would respond suitably, so far as might be possible, to the inevitably unknown variations of other periods.

252. The most notable example of this was the equation for the annual usable amount (Fig. 16):

$$(X+Y) = (X+Y)_{m''} + \delta(A''_{c} - A''_{ct''})$$

By this equation, the occurrence of increases in natural inflows, resulting in greater contents in overyear storage reservoirs, would be followed by increases in usable quantities, in gradual steps and without sudden fluctuations. Provided the usable amounts so computed were actually fully used, or released, within the year, the risk of having to spill large excesses accumulated in overyear storage would be avoided, or at least greatly reduced. Without the data of tributary inflows for 1870–1904, it had not been possible in the investigation to test the programme over that period. But Mr Allan was not without hope that reasonable figures for these tributary inflows might be derived from the recorded natural flows at Aswan, and so make such a test possible.

253. Mr Black had discussed the possible effects of re-arranging the order of the 48 years in various ways, and had expressed some surprise that the Authors had not "shuffled the cards". This had been due primarily to limitations of time and funds. Mr Allan would, however, also raise the question of how far the actual successions of natural events could be regarded as quite unconnected. Their values, treated statistically, in many respects appeared to give indications similar to those of random entities. But, pending much more investigation, Mr Allan would prefer, in specific cases, to *derive conclusions primarily from events in their natural order, at the same time taking* into account all available indications of what their ranges of future variation might be.

254. In reply to a point raised by Mr Wilmot, in making a run on the computer, a serial number punched on each input card ensured that they passed through in the correct order.

255. The use of "recycling" in the investigation did not seem to have been made quite clear. As explained in § 35, the results of any run, in terms of $(X+Y)$, could be made to appear more or less favourable, according to the initial and final contents assumed as acceptable for overyear storage. To remove this arbitrary element, and make possible objective comparisons between different runs, it was decided that drawdown in any run should be negligibly small. This, incidentally, gave a conservative basis of comparison. Recycling had been used solely to effect this purpose; there had been no idea that in future practical regulation there should be any stipulation about drawdown over any particular period of years.

256. Mr Allan was a little surprised that no one had commented on the use of target or reference values in regulation. The most notable instances of this, apart from the equation for the annual usable amount already mentioned (Fig. 16), were given by the Mongalla–Aswan equations in Figs 5a and 5b, each of which included two target values. Another example occurred in Fig. 3. His experience in the Nile investigations had convinced him of the great value of such devices in practical regulation. Other interesting features of the programme were the equations (Figs 13 and 14) to control the discharges from Fourth Cataract and Semna Reservoirs so that, if required, these were kept in phase with High Aswan Reservoir, and thus enabled the available capacity of them all to be used to the greatest advantage.

257. In answer to Mr Fitt, it would certainly have been desirable to test more than two values of the ratio $X{:}\,Y$, and the Authors had intended to try a value intermediate

between 2:1 and 3·5:1. But limitations of time and funds had made this impossible. Mr Allan had, however, no reason to suspect that the results would have been inconsistent with those obtained. The end of June (Victoria date) was chosen for the end of the hydrological year merely because in almost all years, the computed contents of High Aswan Reservoir were then at their lowest for the year. Mr Allan agreed that 1 month earlier would suit the Sudan better, and apparently would not be otherwise unsuitable.

258. In the investigation, foresight had been used only in the very limited sense that if any specified scheme of control, or specified limits of parameters in it, were found on test to be unsuitable, the Authors had made modifications, and tried again. But care was taken to ensure that throughout the computation, the computer would operate only on information which would have been available to a human calculator at the time that each step would have had to be worked out. For example, in the Mongalla–Aswan equations (Figs 5a and 5b), the values of Aswan content used had been those for Victoria dates 2 months earlier. There had been only one small apparent exception to this, in the arrangement, rarely necessary, for raising the discharge at Semna to some specified minimum figure for firm power, by increased drafts on the Upper Blue Nile and Tana Reservoirs (Figs 9, 10, and 14). In the computation, the machine went back to these reservoirs and altered the flows from them, or one of them, as necessary. In practical regulation, additional water would have been released from Semna Reservoir, and replaced there after the normal time lag by a corresponding quantity simultaneously added to the flow from the upper reservoir. The overall effect would have been exactly the same. It was therefore fair to say that in the computations, foresight had not been assumed.

259. The important question of forecasting future discharges was quite different. It would be clear that the programme used included no predictor element. The contributions of Messrs Robertson, Scott, and Cochrane were of great interest. The field was vast, and appeared to be one calling for somewhat specialized study. Mr Allan would only say that even a relatively small measure of ability to forecast the trends of future inflows would add greatly to the resources of those responsible for the regulation of river systems. He suggested that in studying this question, computers might prove to be of immense value.

260. The use of a computer to work out day-to-day regulation instructions in the future, as contemplated by Dr Addision, would raise problems different in certain respects from those of mere simulation of the past. Mr Allan agreed that the programme required would probably be even more complex. But with computers of greater capacity and speed, such as were even already available, and with the further development of computer techniques, he was sure that the problems could be dealt with, with much resulting benefit in the control and use of the waters of the river.

261. As regards the economy in man-hours arising from the use of the computer, raised by Mr Griffin, Mr Allan had estimated very approximately that one 48-year run, i.e. 576 repetitions of the programme, might have required at least 1,200 to 1,500 man-hours, if not more. The machine did this in from 25 to 50 min, according to the number of items for which results had to be punched out, the rate of punching these cards being one of the main limiting factors. The sorting and tabulation of the result-cards might take 30–40 min more, after which full sets of figures were available on paper for inspection by anyone.

262. In the investigations, the respective shares of Egypt and the Sudan had both been computed as at Aswan. It was interesting to note that this principle had also been adopted in the Agreement of 8 November, 1959, between the two countries, which would have to agree about the assessment of the equivalent amounts to be taken by the Sudan at the actual points of offtake. How either country used its share was entirely for it to decide.

263. Mr Allan was grateful to Mr Binnie for his description of the Tigris computations. Of the two rivers, the Nile system was the more extensive, with a larger number of control points and reservoirs. On the other hand, the Tigris system, with its link

canals between tributaries and its offstream reservoirs, offered in certain ways more alternatives in regulation. Mr Allan agreed with Mr Binnie that the formulation of its computer programme had been correspondingly more complex.

264. How far digital computers could be used on other rivers largely depended, in Mr Allan's view, on the character and extent of the data available, in relation to the problems to be investigated. Only computer experts were really competent to express firm opinions, but Mr Allan was inclined to think that any river problem capable of expression in mathematical form could be dealt with; it would be primarily a question of the type and capacity of the computer needed in any particular case, and of whether the cost and time required for the production, testing, and use of a suitable programme would be justified by the results in prospect.

265. Mr Allan had no personal experience of analogue computers.

266. With regard to the comments made on the scheme of Nile development assumed in the investigation, Mr Allan first wished to stress again that the investigations had been made on considerations of hydrology and topography only, and that its results were subject to further studies, particularly economic.

267. Dr Hurst, in his very valuable contribution, had shown that for the natural flows at Aswan over 1905–52, k in his equation $R/\sigma=(N/2)^k$ was only 0·53, compared with a mean value of 0·73 over a wide range of different natural phenomena. He had deduced from this that valid conclusions as to future overyear storage required could not be drawn from such an unusual set of years. It had seemed probable to him, on present knowledge, that capacity did not exist in the Nile Basin to make possible full use of the recorded flows from 1870 down to the present time. He had also pointed out that over different periods, mean flows, standard deviations, and values of k could all vary.

268. It appeared to Mr Allan that reservoir capacities required for overyear storage could only be satisfactorily determined if account were taken of the losses resulting from the storage, as well as of the inflows and drafts. The variable to be regulated could be stated as the annual inflow less the annual loss. Dr Hurst's well established general equations, of which full use should be made, did not, and probably could not, include a term for losses, which would necessarily be specifically related to the circumstances of each individual case. At present, so far as Mr Allan was aware, the only available method of calculating the storage required in any particular case, with due allowance for losses, was the rather tedious process of working out actual regulations. He fully agreed that in the case of the Nile it would have been most desirable to do this from 1870, had the requisite flow data been available for the full period.

269. But two other considerations also arose. First, if the draft was to be constant, the longer the period investigated, not only the larger the reservoir required, but also as a result the greater the mean losses involved. It was quite possible to conceive a reservoir which would be too large to give the optimum net constant draft over a recorded period. Secondly, in actual regulation with the future flows quite unknown, any constant draft assumed would be more than likely to prove, in the event, too large or too small. Dr Hurst had discussed, in reference 7, the advantages of variable drafts, on various different methods. It seemed to Mr Allan that in practice the fullest possible use of water was likely to be obtained by the use of a draft which was self-adjusting by gradual changes in accordance with the trends of the variations in the natural inflows less the losses, using some systematic method of determination each year, such as had been described in the Paper to determine $(X+Y)$. If this was so, it appeared only logical to use similar methods in the studies of past records. Fresh problems would arise, for example, how to secure an objective comparison between two different studies of the same inflow data. But in general, investigation on such lines appeared to Mr Allan to offer the best prospects of further progress. An important point was that ranges of capacity required over periods with differing conditions would vary much less than if constant drafts were attempted.

270. Mr Black's analysis over 1905–52 for the High Aswan Reservoir alone, without

other storage on the Nile, was very interesting. However, it would appear from his description that he had used only yearly totals; if this was so, presumably his required range of 40–116 milliard m^3 did not include the capacity needed for the annual storage of each flood until the succeeding low season, which in a mean year might be perhaps about 13 milliard m^3 more. The range worked out in the Paper, being derived from monthly calculations, had allowed for this.

271. Mr Griffin had rightly pointed out that overyear storage did not provide a mean benefit of 80 milliard m^3, but merely increased the figure from 52 to 80. But even the 52 milliard could not be assured; the total flow of the Nile in 1913–14 had been only 42 milliard, and in 1899–1900 63 milliard.

272. Considering next the Ethiopian tributaries of the Nile, Mr Black, with his wide personal knowledge of the region, thought that a suitable site was not likely to be found in the canyon of the Blue Nile for a reservoir of 18 milliard m^3. He also held that 75 million m^3/day, as an occasional maximum, was far beyond the capacity of the channel of the River Balas. His views must be respected. Mr Bolton, on the other hand, offered the prospect of reservoirs on the Blue Nile, the Didessa, and the Tekazze, totalling about 150 milliard m^3. He further suggested that by such developments, in place of reservoirs farther downstream, including part of the High Aswan Reservoir, the overall evaporation losses might be reduced by as much as 7–8 milliard m^3 annually. It would be most valuable to see the surveys on which these very large prospects were based; meantime, Mr Allan would prefer not to comment on them. Up till the present, lack of information had been the great difficulty in considering development in Ethiopia, and this alone had necessitated the question marks in the Paper against her future needs of water. It was encouraging to learn that these were now being studied and formulated. It was not correct to say that the agreement of November 1959 between the Sudan and the United Arab Republic ignored the needs of Ethiopia; it specifically envisaged discussions with other countries about their shares in the Nile.

273. Most of Mr Bolton's other points were dealt with jointly with those made by others. With regard to the need for maintenance of the spill capacity of the Rosetta and Damietta outlets of the Nile, it must be remembered that with the High Aswan Reservoir in operation, the flows from it would be clear, though these no doubt would pick up some silt in passing down the river channel. As regards his general comments, Mr Allan had long been of the opinion that if the maximum possible benefits were to be ensured, the whole of the Nile Valley should be treated as a hydrological unity.

274. Conservation of flows at present lost in the basin of the Bahr el Ghazal had not been brought into the investigation only because quantitative information of the inflows over 1905–52, and of the savings which might be possible, had been far from complete. A good deal of information about these points had been collected in recent years, but had not yet been published. It was, however, clear that the potential benefits were considerable, and though the hydrological and engineering problems might not be easy, Mr Allan had no reason to think them insoluble.

275. With regard to the Equatorial Lakes, it should be explained that in 1948, a range of 3 m in Lake Victoria had been contemplated, to give a gross capacity of 200 milliard m^3, with the object of regulating the outflow in the interests of irrigation in the Sudan and Egypt, above a specified minimum rate of discharge for firm power for Uganda. Later, Uganda had indicated that she would prefer to maintain the flows out of Lake Victoria, and out of Lake Kioga also, as near to the long-term natural means as might be possible; in view of this, she could contemplate a somewhat larger range of storage in Lake Albert. The control equations for Lake Victoria and Lake Kioga given in the Paper had been devised accordingly, with the result that the range in Lake Victoria had decreased to 120 milliard m^3. Incidentally, contrary to Mr Black's surmise, these control equations operated quite independently of the storage in Lake Albert. If, in the future, Lakes Victoria and Kioga were controlled on these lines, the suggested use of the remaining 80 milliards of capacity would be out of the question. It was to be noted that because of its very great area, natural variations of content and level in Lake

Victoria could occur, which could not be entirely controlled by regulation of the outflow through Owen Falls Dam, even if this could be varied as required between zero and its natural maximum, in contrast to the steady flow now sought. This was relevant to Mr Wilmot's contribution.

276. The extent to which storage in any of the Equatorial Lakes could be used to adjust flows in the Main Nile, north of Khartoum, was limited by the need to observe certain maximum and minimum rates of flow in the Bahr el Jebel, in the interests of the safety and well-being of the peoples of the "Sudd" region. In reply to Mr Fitt's enquiries about these minima, it was hoped that the Lake Albert–Nimule reach could be kept navigable at zero flow by a low dam at Nimule, and that the minimum of 0·57 M/M in the Jonglei Canal, rarely required, would suffice to inhibit weeds. But further studies would be necessary.

277. The difficulty of time lag from the Equatorial Lakes to Khartoum, also mentioned by Mr Fitt, could be overcome by releasing extra water from the High Aswan Reservoir, pending its replacement by corresponding additional amounts simultaneously released from Lake Albert.

278. The possibility of conserving water by drainage of swamps in Uganda, mentioned by Mr Griffin, was one on which Mr Allan had no specific information, but he was sure that the experts of the East African countries were fully alive to such potential benefits, the development of which could only be welcomed. The idea of reducing evaporation in Lake Kioga by lowering levels had not been studied by the Authors because a certain range of capacity in that lake had been found necessary.

279. Mr Underhill had commented that the proportion of total storage capacity to mean annual flow appeared to be much larger for the Nile than for other rivers, for example, the Tigris. Others, in contrast, had made the point that some additional capacity should be made available on the Nile, to cover future unknown variations. Margins for contingencies were certainly necessary, but it was important that in operation they should not unnecessarily increase the evaporation losses.

280. The need for flood protection, particularly for Egypt, had been stressed by Dr Hurst and Mr Simaika. Mr Allan would in no way question the provision of 30 milliard m^3 in the High Aswan Reservoir, earmarked for this purpose. He thought, however, that it was relevant to keep the following points in mind. In the Plan described in the Paper, storage in reservoirs on the Blue Nile, Atbara, and Main Nile would always be considerably drawn down before any flood, below the highest contents reached in the immediately preceding year; in the case of overyear storage reservoirs, such highest contents would only extremely rarely be their full capacities. The total of such drawdowns, on a conservative assessment, would be at least 25 milliard m^3. This had to be filled by a rising flood before, even in extreme conditions, reservoirs could be full. In almost all years, the margin to be filled would be greater. It must further be remembered that normally the discharge passing down from Aswan would be no more than the current requirements of Egypt; as soon as there was any indication of the possibility of extremely high conditions, this discharge could be increased up to the safe capacity of the river channel, even before any actual necessity to spill water from a full reservoir had arisen.

281. With regard to the order of priority of future projects, raised by Mr Wilmot, Mr Fitt had pointed out that the indications of the computations should be regarded as preliminary, and that each project would require careful investigation and scrutiny. Mr Allan fully endorsed this view, and would prefer not to prophesy about priorities at present. It was true, however, that the Jonglei Canal scheme was attractive, because it would actually provide additional water, and not merely redistribute what was naturally available, at the cost of loss by evaporation.

282. In conclusion, Mr Allan wished to express the grateful thanks of the Authors to Mr K. E. Snelson for expert help in the investigations; by an oversight his name had been omitted from the acknowledgements made in the Paper.

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APPENDIX I

RANGES OF CONTENT AND LEVEL OF RESERVOIRS AS ASSUMED IN THE INVESTIGATION

	Range of content: milliard m³	Range of level: metres
Reservoirs for overyear storage		
Lake Victoria	120 (200)	1·8 (3·0)
Lake Kioga	10	2·6
Lake Albert	100	16·2
Lake Tana	15	5·0
Upper Blue Nile	18[1]	?
Semna	25[2]	60·0
High Aswan	100[2]	68·0
Reservoirs for annual storage (cyclic)		
Baro	5·5	?
Roseires	6·5[3]	50·0
Sennar	0·9	15·7
Khashm el Girba	1·1	28·0

[1] Including 3 milliard m³ for flood protection.

[2] Not including a margin for flood protection.

[3] Capacity will actually be 7·6 milliard m³.

APPENDIX II

SOME PUBLICATIONS RELATING TO NILE DEVELOPMENT

"The Basin of the Upper Nile", Sir William Garstin. 1904.

"Report of the Nile Projects Commission". Cairo. 1920.

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