Paper No. 6309

Habbaniyah flood-relief and storage scheme†

by

Reginald Duncan Gwyther, C.B.E., M.C., M.Sc., M.I.C.E.

Alfred Proom Humble, M.B.E., M.I.C.E.

and

Richard Kenneth Lewis, M.I.C.E.

Discussion

Mr William Allard (Consulting Engineer) observed that, although it was not the intention of the Authors to convey such an impression, an engineer, reading their Paper, might think that there had been some vacillation and uncertainty in the planning of the work described, and even, perhaps, in its execution. He would, therefore, recall the circumstances in which the work had been begun. In 1928 (taking that as the basic date) Iraq had been a kingdom for only 7 years, having previously been three separate provinces of the Turkish Empire. Since 1908 it had had a Turkish government, a British military government, a British civil government and, for the past 7 years, an Arab government without previous experience of such responsibility. It had had no public debt, but equally no credit with the bankers, while its income had been very small. It had a population of three million in a country the size of the British Isles. The Government budget per head of the population had been 30s. In Egypt, with a population of 15 million, it had been about £3 per head, and in the British Isles at that date, with a population of 49 million, it had been £15 per head.

110. On the hydrological side there had been an almost complete absence of data. Willcocks had measured whatever water happened to be there at the time of his survey, and in 1928 some proper persistent measurements had begun, but the first year had been a very difficult one, and it had not been until 1929 that things had really got going; and, with the luck which was sometimes experienced in such matters, that had been a bumper year, with the highest Euphrates flood for at least 36 years. Willcocks, Mr Allard believed, had measured a maximum of 3,000 cumecs and had thought that allowance might be made for 4,000 cumecs, but in 1929 a member of the Institution, G. E. Meade, had measured 5,000 cumecs daily flow, and for a few hours, 5,500 cumecs. This matter was touched on in §§ 10 and 18, and in § 52 it was stated that that figure had been revised to 5,200 cumecs.

111. In § 21 there was a description of how what the Americans called a plug in a levee, a breaching section of the river embankment, had been cut and the flood-water let into the Habbaniyah Lake. As the Authors had pointed out, such action could have effects on the bed-level of the river when there was so much material moving. The result had been that the gauge-reading which had been taken as an index of danger would vary from year to year, but only gauge-readings without any related discharge measurements had been available. It had only been when discharge measurements began to be made in 1929 that it had been possible to get a grip of the position, and it had been a great problem to decide on the river level to which the works should be designed.

112. From § 6 it might seem that there was inaction for some years before the record

† Proc. Instn civ. Engrs, vol. 11, p. 405 (Dec. 1958).

flood of 1929, but this was not so. When Mr Allard had taken charge, in the autumn of 1928, he had at once been told by King Feisal I that he wanted proposals for the Habbaniyah Scheme, and Mr Allard had been given about 6 months to produce them. It had been in the middle of the flood, when every other engineer of the Department had been out in the field, that he had sat trying to write his report in the light of the gauge-readings which had been coming in at that date, and he had given it to the King during the flood. The necessary administrative steps had then been taken and in 1932 Messrs Coode & Partners had been commissioned; but the engineers had not been idle meanwhile in improving their calculations. Even today the discharge measurements which were being used were obviously only such as had been obtained within the past 30 years, so that what the 100- or 200-year flood would be was still not known. It would be as well if arrangements were made to trap some of the water up-river, as Mr Gwyther had hinted might be done.

113. Among the best things that had been done for the information of contractors was the digging by hand of a pit in the deepest part of the Dhibban cut. Fig. 6 showed that, since the pit was down to the design level, it was about 100 ft deep, and towards the bottom the earth was of a remarkable character. It was like very hard chocolate, and working on it with a pick or other hand tool merely left shallow grooves on the surface. It was similar to the soil which he had found in the Sudan Gezira, where it was generally classed as loess, and, it was said, to the soil known in the United States as "gumbo", which was recognized as a very tough material to excavate. One of the firms which visited the work in Iraq, however, had discovered that by pouring buckets of water on it this very tough material at once became extremely soft, and the possibility of hydraulic excavation had been considered. In §§ 34–36 the Authors had referred to a number of difficulties with the excavators and the dredger in different lengths of the cut and at different times. What had hampered the work; had it been the nature of the soil, the lack of elbow-room for the excavators, or the deepness of the cut and the difficulties of removing the excavated material?

114. In the days when the scheme had been in preparation there had also been plans for a railway between Baghdad and the Mediterranean. Those concerned with the scheme for the river came to know the ideas of the engineers of the Iraq Railways for crossing the Warrar depression (see Fig. 1) and it had been surprising to find the very generous extent to which they had provided openings for the passage of flood-water. That was a subject which was now coming to the fore again in the United Kingdom, where great new roads were being built across river valleys. He understood that the Hydraulics Research Station at Wallingford had done some investigations on the subject and had shown what valuable economies could be achieved by the use of proper methods of design.

115. The Authors had mentioned the brackishness of Lake Habbaniyah. Originally there had been a good deal of anxiety about what might happen when the lower waters of the lake were drained through the Dhibban cut back into the Euphrates. It had been thought that extremely salt irrigation water might reach the fields. Could the Authors give some details of the investigations which (Mr Allard believed) had been made into the actual salinity of the water in the Habbaniyah and Abu Dhibbis depressions, and of that which returned to the Euphrates when the Lake was first discharged through Dhibban?

116. The total cost was given in Table 4 as roughly £4,400,000, of which slightly under £1,600,000 was debited to the Ramadi barrage and lock, so that for the inlet works, the Dhibban channel, and the Mujarah cut the total was about £2,800,000. When the work had been put out to tender in the 1930s the cost had been £1,200,000. In view of the length of time over which the work had been spread, the great rise in costs which had occurred during that time, the chopping and changing, and the very many difficulties of those who had been trying to control expenditure, he thought that the advance in cost from £1·2 million in 1933 to no more than £2·8 million at the present time was of very great credit to both the contractors concerned and, above all, the consulting engineers who had advised the Iraq Government in this matter.

Mr. M. G. Ionides (formerly of Iraq Government Development Board) said that he would discuss the scheme as a part of the whole river system of Iraq, so taking the story on from the time that the works which the Authors had described had been finished.

118. Fig. 18 was a schematic representation, reduced to its simplest form. On the left there was the River Euphrates, the inlet into the Habbaniyah Lake, and the outlet into the Abu Dhibbis. Since the works described in the Paper had been completed, the Development Board had taken two decisions. One was that the Abu Dhibbis would not, for various technical reasons, be used as a reservoir, but would be kept simply as the "last ditch" into which to put excess flood-waters, which would then evaporate. The second decision was that this cut (C in Fig. 18) from the Habbaniyah Lake to the Abu Dhibbis, should be enlarged so as to match the inlet, the point being that the functions of the Habbaniyah Lake as a flood escape and for storage could then be performed completely separately. For example, if the Habbaniyah was completely full at the beginning of the flood it would be possible to pass the whole flood straight through the lake into the Abu Dhibbis.

FIG. 18

119. On the Tigris, the Board had completed the inlet into the Wadi Tharthar by the time of the 1956 flood, so that there had been that enormous advantage, though for flooding protection only. The use of the Wadi Tharthar had been proposed by Willcocks many years ago, and in the late 1940s Mr F. F. Haigh, the Chairman of the Irrigation Development Commission, had recommended², as a result of his studies, that it should be used not only for flood protection but for storage; in exactly the same way as the Habbaniyah, with outlets back into the Tigris and into the Euphrates. Fig. 18 showed what Haigh had called the "virtual feeder", by which Euphrates water could be virtually stored in the Wadi Tharthar.

² References 2 *et seq.* are given on p. 565.

120. After Haigh had reported, some doubt had been cast on the technical possibility of using this lake as a reservoir; questions of seepage, salinity and evaporation, had been raised. At the beginning of 1956, therefore, the Development Board had commissioned another firm of consultants, who had had no connexion with what had been done earlier and had not, therefore, committed themselves in any way, to make a complete investigation.

121. When Mr Ionides had left the Development Board in the spring of 1958 these consultants had committed themselves on paper to a confirmation of Haigh's findings², namely that the Wadi Tharthar could be used also as a reservoir. Mr Ionides now proposed to assume that it had been decided to use it in that way, providing means of getting the stored water back into the Tigris and into the Euphrates; on that basis he made some forward prognostications. The "virtual feeder" had been one of Haigh's ideas. It was quite simple in principle. Through this feeder (F in Fig. 18) it would be possible to pass water from the Euphrates into the Tigris; and at the same time (or at any other time) pass an equivalent quantity out of the Tigris into the Wadi Tharthar. That virtually meant the storing of Euphrates water in the Wadi Tharthar. The reverse was also possible, and water could be sent from the Tigris to the Euphrates and an equivalent amount from the Euphrates into the Habbaniyah. From the point of view of the Euphrates it did not matter if the water which came back into it in the summer came from the Habbaniyah or from the Wadi Tharthar; it meant the same thing so far as irrigation lower down was concerned.

122. Mr Ionides did not propose to go into quantities, but with such a system as he had described the Habbaniyah and the Wadi Tharthar would be operable as one hydraulic unit. In addition, there were the Dokan dam on the Lesser Zab and the Derbend-i-Khan dam on the Diyala River. Taking those four together, there should be enough trunk storage capacity to make it possible to match the variable flow coming down from the hills to almost any pattern of demand. The average annual flow of the two rivers together was about 600 milliard cubic metres. The four reservoirs together would give a live storage of between 30 and 40 milliard cubic metres, and possibly more, so that his general conclusion was that it would be possible to provide almost complete balancing of the natural supplies to the pattern of agricultural demand.

123. The Paper mentioned that a former Director-General of Irrigation in Iraq, Mr F. S. Hardy, had said that it was necessary to be careful about the regime of the river Euphrates downstream of Habbaniyah, to see that it did not deteriorate. Mr Ionides entirely agreed with that; in present conditions. But when there was complete control, plus the possibility of control up the Euphrates in Syria and Turkey, and when the stage was reached when the last drops of water were beginning to be needed, he believed—it would happen gradually—that the rivers from those points downwards would assume both the functions and the shape of canals. At that stage one could no longer afford to send flood-water down to flush them out and keep them as flood channels. As the years went by they would literally become canal systems. By that time—it would take a generation or two—it was to be hoped that all the way down on both rivers the drainage system would be completed and irrigated agriculture would be intensified and enriched; and that if any further protection from catastrophic floods was required, it would be provided by dams upstream or by enlarging the inlets to the Wadi Tharthar and Habbaniyah.

Mr Herbert Addison (Consultant) quoted from Mr Ionides's letter to *The Times* of that day:

"The basic problem in the under-developed countries is how to release and guide the energies of hundreds of millions of pairs of hands which are locked up, under-employed, in the rural subsistence economy. They work when the season needs it, eat what they grow, and their use of cash is marginal."

Did the Authors consider that those words formed a valid criticism of the admirable project which they had brought to completion? Judging from § 102, probably they

would not. They had pointed out that as a direct result of the Habbaniyah Scheme, additional rice, other vegetables, fruit, millet, wheat, and barley had been grown to the value of nearly 3 million dinars in one year alone. That should have found employment for a number of pairs of under-employed hands.

125. Turning to the technical aspects of the Paper, the mention of the name of Willcocks, who had made his name in Egypt, naturally invited readers to trace the influence of Egyptian irrigation practice on constructional work in Iraq. So far as the control structures were concerned—the barrages and regulators—the resemblance was very close. In all the structures which had been described, the width of the openings, 6 m, and the thickness of the piers, 2 m, were identical with those of the Nag Hammadi barrage on the Nile, and the scour prevention devices recalled those in Egypt. The baffle weir in the vents and lip wall extending across the apron resembled those on the Assiut barrage on the Nile, as remodelled. A significant addition was the trough or bucket down-stream of the apron.

126. At least in one instance those protective devices had been extremely effective. According to § 105, the flow of water down the Mujarah escape channel had been so heavy that in places far distant from the regulator the channel bed had been eroded, as shown in Fig. 5, to a depth of about 5 m, yet apparently the bed near the regulator itself had been undamaged. The Authors believed that retrogressive scour in the channel would ultimately endanger the regulator only if discharges of the magnitude in question were allowed to continue in the future. In that connexion it might be recalled that the late Mr J. D. Atkinson did much to develop this particular type of lip wall protection. Otherwise, only in one small matter did the regulators have to meet unusual conditions. Some had to withstand a reverse head; the head might be sometimes on one side of the gates and sometimes on the other. Perhaps the Authors would say whether or not this had created any difficulties in design or in working.

Mr William Brown (Contracts Manager, Middle East, Messrs Balfour, Beatty & Co. Ltd), commenting on the Paper from the contractor's point of view, said that there had been no major engineering problems, apart, perhaps, from the Ramadi barrage, which was outside his province; but a few difficulties had been experienced, particularly in regard to some of the plant.

128. The Habbaniyah Scheme had occupied a period of about 40 years, and there had been great changes in the types of plant used. In 1914 all the work had been done by hand and with the use of donkeys. When Mr Brown's firm had tendered for the work in 1932, the major hazard had been the Mujarah escape channel. In the case of the channel at the Warrar end there was ordinary soft sandy soil, with clay and bands of conglomerate, which could be dealt with by dragline, but at Mujarah there was a very hard baked clay, almost the consistency of a marl. In 1932 they had thought that explosives would have to be used, and the problem had been one of how much explosive to use. They had put in a price of 2s 6d/m³. The scheme had been abandoned. In 1936 at Kut they had dealt with a similar channel, 2 miles long, with tractor and scraper units. That had been the first time that they had had an opportunity to use them, and they had been very successful. The ground had been fairly straightforward, and he thought that the price had been about 6d/m³. As a result, when they had re-tendered and had been awarded the scheme in 1939, they had gone on the Mujarah cut with tractor-scrappers. The Authors had referred to this in §§ 23 and 24, and in § 24 they had given the output obtained and had said that the result was considered to be satisfactory. Mr Brown agreed, but there had been endless difficulties in finding a way to break up the ground, because the rooter teeth supplied with the machines became rounded and worn down in a matter of hours. They had at that time been dependent upon their own resources, and after a great deal of experiment they had overcome the difficulty by welding pieces of old scraper blade (the hardest material which they could get hold of at that time) on to the leading edge of the standard teeth. It had proved very successful. The secret lay in the angle of the scraper blade to the teeth, so that as

the under-side became worn a sharp edge could always be kept on the teeth; even then the teeth had to be changed every 8 or 9 hours. By that means they had been able to root down to a depth of 8 to 9 in. without using any explosives, and the work had been completed in 21 months, just in time for the first exceptional flood in 1941, when the scheme had been brought to a standstill by the disturbances in Iraq. The rooters had been drawn by D8 tractors. The ground was so hard that in many cases it had been possible to use only one tooth on the rooter, or two at the most, but one rooter had kept two or three scraper units going.

129. On the Dhibban channel they had used two Monighan walking draglines—an innovation at the time. They had proved extremely useful. They had had 44-cu.-yd buckets and a boom radius of 125 ft. The main difficulty had been to teach the drivers to handle them—with 10 tons of wet muck in a bucket swinging round a 125-ft radius. Their use began before the war, and after the war they had carried out further excavation on the Warrar inlet.

130. After the war the Ramadi inlet channel had been abandoned in favour of the greater capacity and better location of the Warrar channel. For this his firm had used a 16-in. cutter-suction dredger. The Authors had dismissed this rather summarily in § 57 by saying that it had been unsuitable for certain parts of the ground and suffered delays due to mechanical breakdowns. That was true, but, in fairness to the contractors and to the makers of the dredger, it should be explained that the main trouble had been the very abrasive nature of the soil, which perhaps had not been sufficiently appreciated. It had been necessary to renew the liners in the pump casing, and, although the makers had provided a casing more than 2 in. thick, after a few months it had suffered from excessive wear. The contractors had again had to improvise, and had overcome the trouble eventually by lining the casing with leaves of old lorry springs in hardened steel. That had been very successful, and in the end they had excavated about 750,000 m³. The best output which they had obtained over a 6 months period had been 206,000 m³.

131. It was a great credit to Sir William Willcocks that the scheme had been finished 40 years after his survey more or less in accordance with his original plan.

Mr B. M. U. Bennell (Sir Murdoch McDonald & Partners, Consulting Engineers) referred to the design of the floor against uplift pressures. Had the provision of a drainage blanket been considered? This might have helped to make possible a reduction of the thickness of concrete shown in the drawings. It appeared that these blankets had not normally been employed in barrages designed and built in India and the Middle East, but they had been used in the United States, presumably with success, and notably in the flood-diversion regulators on the Mississippi. What was the Authors' opinion of the efficacy of these blankets?

133. A sill was provided down-stream of the Warrar Regulator gates to break off the jet, but was this adequate to ensure that the hydraulic jump would fall on the apron when the lake water was low and a large initial diversion was required from the Euphrates? Had the provision of a depressed floor to form a stilling basin, in which the hydraulic jump would be certain to fall, been considered for this regulator?

134. It seemed dangerous to risk the frequent passage of flood-water, heavily charged with sediment, through Lake Habbaniyah to the Abu Dhibbis depression. It was inevitable that the useful storage available would be reduced by deposition in Lake Habbaniyah. How many years were expected to elapse before the dead storage of the lake became full of sediment? Had the provision of a separate flood escape from the Euphrates to the Abu Dhibbis depression been considered, to mitigate this?

Mr A. S. Stokes (Director, Ransomes and Rapier Limited, Ipswich) gave some details of the sluice gates. The barrage itself had twenty-four gates and the Warrar regulator also had twenty-four; the Mujarah regulator eight and the Dhibban regulator five. All these gates were 6 m (19·7 ft) wide and varied in depth from 8 to 5 m (26·25 to 16·4 ft) according to their position. They were all of the wheel type (i.e. mounted on wheels) with axles of rather special design, with the exception of the Dhibban gates

which, because of the greater head under which they operated, were of the Stoney roller type.

136. The special design, evolved in collaboration with Mr Alec Vaughan-Lee, provided that the wheels were bushed with one kind of gunmetal and revolved on steel sub-axes which were themselves "clothed" in a different type of gunmetal, so that the possibilities of seizure were diminished, if not entirely removed. The grooves were all of Meehanite, never less than $1\frac{1}{4}$ in. in thickness, and the skin plates of the sluice gates had a minimum thickness of $\frac{1}{4}$ in. against corrosion. The gates were counterbalanced with the intention that they should be manhandled by four men in the absence, or in the event of failure, of power.

137. The lock gates were of the type that rose vertically and, on reaching the top of their movement, folded over into a horizontal position and so were out of sight and, less "in the wind". That was not a novel idea, for such gates had been built, in 1896 under the bridge at Richmond where they were still working.

The following contributions were received in writing.

Mr W. N. Allan (Irrigation Consultant to the Government of Sudan) noted that Figs 3 and 4 and Tables 1 and 2 showed how the scheme (whose primary function was flood relief) would provide effective protection in years like 1929 and 1940, limiting the flow below Ramadi to the safe maximum figure of 2,600 cumecs (§ 19). It did not appear, however, that the scheme in its present form could be relied upon to provide full protection in any year which might be expected to occur. The design capacity of the Warrar Inlet, at 2,700 cumecs, would apparently suffice to reduce a peak river flow of 5,300 cumecs to the safe maximum. The maximum flow recorded at Hit was given in Table 1 as 4,700 cumecs, but § 52 stated that there was some doubt whether this figure should not have been 5,200 cumecs. Mr Allan presumed that flood flows in the Euphrates depended to a considerable extent on the rates of snow-melt in the mountains of Turkey, and it might be that their range of variation was somewhat less than that of rivers whose flows derived entirely from rainfall. Even so, he suspected that flood peaks might occur, considerably greater than any so far recorded, particularly because the period of records was, he believed, not very long. Had analytical studies been made to investigate what the maximum long-term flood flow might be, and could the Authors provide information about the recorded data?

139. No doubt the increased storage which would become available when the maximum level in Lake Habbaniyah was raised to R.L. 51·00, and the enlargement of the Abu Dhibbis Escape to take 1,600 cumecs, would be of great value if a prolonged period of high flows should occur. But it appeared that the critical factor must remain the capacity of the Warrar Inlet and channel. The slopes of the channel were relatively steep, and the Paper stated that scour was expected to occur. To what extent had this actually taken place since completion of the channel in 1951, and was its capacity, as a result, now greater than the design figure? Was there any possibility that works to limit scour might have to be undertaken?

140. Turning to the use of Lake Habbaniyah to store water for irrigation, it appeared, from the figures given, that the contents above R.L. 46·80 were used to improve supplies for the summer crops, until about the end of September. The quantities available must vary quite widely from year to year, according to the magnitude of the preceding flood. Presumably the natural flows coming down the river at that time must also vary in the same sense. If so, summer irrigation must be very uncertain. In contrast, the contents from R.L. 46·80 downwards, appeared to be assured in all, or almost all, years; the importance of the winter crops on which these contents were used is mentioned in § 100. Mr Allan estimated approximately that the net amounts so available, after allowing for evaporation losses, might average about 1,000 million cubic metres; would the Authors comment on this, and give some information about the quantities of water available for summer crops since the completion of the scheme?

141. It was interesting to consider the characteristics of an off-stream reservoir such

as Lake Habbaniyah, as compared with those of a reservoir of similar capacity provided by a dam across the main stream. For both types, one of the most important considerations was the relation of contents to surface areas, and thus to evaporation losses, at the various levels; this relation, of course, depended on the local topography in any individual case, irrespective of its type. In this respect, one of the worst reservoirs was at Jebel Aulia on the White Nile in the Sudan, an on-stream reservoir. This, with a gross capacity of about 3,500 million cubic metres, in its normal annual regime lost about 3,000 million cubic metres; even so, because the greater part of this loss occurred in the months of the year when the flow of the river exceeded the net requirements of irrigation, in the present stage of development the reservoir was able to make a valuable contribution to the quantities available in the period of shortage each year, for the benefit of Egypt. In respect of sedimentation, the off-stream reservoir might have the advantage, in that only the quantities of water abstracted from the main river could deposit silt in it, whereas in an on-stream reservoir, all silt-laden flows were liable to be checked in their passage through it, and thus caused to deposit at least a good proportion of their load. The benefits of the off-stream reservoir, both for flood relief and for irrigation, were limited by the need to provide inlet and outlet channels of sufficient capacity, as in the case of Lake Habbaniyah; this need did not arise with the on-stream type. A prime essential for the on-stream reservoir was of course a site suitable for the construction of a dam high enough to give the capacity required, and capable under the resulting head of passing safely river flows up to the maximum which might be expected.

142. Off-stream reservoirs were not common. Iraq provided another notable example in the Wadi Tharthar, used so far, Mr Allan believed, only for flood relief. In Egypt, south of the Faiyum, was the Wadi Raiyan, the use of which as a reservoir had first been suggested by an American in the latter part of the 19th century; it was very much deeper than Lake Habbaniyah, but its net capacity for useful storage above the minimum outflow level was of the same order of magnitude. As a project for flood relief and irrigation in Egypt, it had been superseded by the High Aswan Dam.

143. It appeared probable that in most cases the local topography would determine the nature of the reservoirs which were possible, and no choice between the two types would arise. It would, however, be of interest to hear the Authors' views on their relative advantages and disadvantages. In § 107, the Authors had indicated that other works might be built in future upstream from Ramadi, which would help in reducing the flood peaks. Could they give any indications of the possibilities of such works, in type, location, and magnitude?

Mr F. F. Haigh (Haigh, Zinn, & Associates) remarked that the reconsideration of the scheme in 1943, following a series of exceptionally high floods during the years 1940 to 1943, had resulted in recommendations to move the inlet channel from Ramadi to Warrar and to increase its capacity to 2,100 cumecs. The site had been changed in order to obtain better conditions at the offtake. It involved a much longer and more expensive channel and also the abandonment of the work already done at the original site. Provision had also been made for the Dhibban outlet to discharge into the river below the Cantonment, although acceptable to the Royal Air Force, and giving a lower evacuation level, was longer and more expensive. Possible usage of Euphrates water for irrigation, it had subsequently been calculated, would be raised from 280 to 390 cumecs by the scheme.

145. Because of increased cost and war-time conditions, the Iraq Government had kept the case under consideration for some time and, on the formation of the Irrigation Development Commission under Mr Haigh's Presidency in 1946, their advice had been asked.

146. The Commission had suggested² modification of the project to include a river barrage as an essential feature. The reasons for this were:

- (a) It would permit escape to be made at a high level irrespective of river levels, thus enabling the major portion of high flood escape to be passed as spillage over the ground surface and greatly reduce the size and cost of the inlet channel.

- (b) It would enable a higher level to be used in the lake, making additional capacity available and hence making the scheme more effective both for flood control and storage.
- (c) It would permit the higher levels of the lake to be commanded at any time, irrespective of natural river levels, thus enabling the filling of the reservoir for storage to be delayed until the end of the flood season and capacity to be reserved for flood control to a late date.

147. Features of the scheme suggested by the Commission were:

- (i) The reservoir range to be from 42.5 to 51.0 m. The corresponding gross live capacity being 2.68 milliards, of which evaporation would account for 0.68 milliards leaving a net live capacity of 2.00 milliards, enabling usage to be raised from 390 to 440 cumecs, and the maximum river discharge to be reduced to 2,000 cumecs.
- (ii) The Barrage to be located at Warrar, where river levels were suited to the command of a 51.0 lake level, and the danger of waterlogging Ramadi town would be avoided.
- (iii) The inlet regulator to be given a capacity of 3,200 cumecs corresponding with a probable maximum flood of 5,200 cumecs, and the barrage's capacity of 3,000 cumecs permitting control to 2,600 cumecs in the early stage.
- (iv) The longer Dhibban alignment to be used since this would permit a lower level to be worked to in the reservoir, but its capacity to be reduced to 200 cumecs.
- (v) In the first stage the reservoir would be operated to the 49.5 level only, thus avoiding the necessity of raising the dykes and remodelling the Mujaarah Regulator. A capacity of 2,700 cumecs only was to be provided in the inlet channel, which it was thought might develop automatically by erosion to the final capacity.

148. The Commission's proposals had been accepted by the Government and it was satisfactory to know that the first stage had been completed. The Commission had also supported the extended use of the Abu Dhibbis for escape and eventually for storage as originally suggested by Willcocks.

149. The engineer's task in Iraq would not be finished until flooding was completely prevented to a sufficient extent to make possible the reclamation of the marshes of southern Iraq, and until the maximum use was made of river waters for irrigation, which maximum would be limited by the water supplies and not by the area of the land. To this end, further use of the Abu Dhibbis was indicated. As a first step a return channel to the river was required to enable the storage to be evacuated and to provide room for more escape before the flood season. Eventually, of course, the stored water would be used for irrigation and the discharge regulated to that end, raising possible usage of Euphrates water to 510 cumecs. A difficulty in this connexion was that the salt content of the depression was so great that water from it could not immediately be used for crops. However, while the lake was being used for flood control, the escape water could be used to evacuate the salts and reduce the salinity to a permissible figure. This, it had been calculated, might take about 4 years having regard to the necessity of limiting the salinity of the total river supply during the process.

150. The corresponding flood control and storage scheme on the Tigris was the Wadi Tharthar scheme, which had also been completed up to the first stage. Here, salinity was not likely to give trouble, provided a return channel was constructed in a reasonable time. The doubts in the case of the Wadi Tharthar concerned its watertightness, but these again could be dispelled or confirmed from experience while it was in use for escape only and Mr Haigh believed that results to date were promising.

151. He had recently flown over Iraq on a journey to Pakistan and had been interested to see the Habbaniyah works and the Wadi Tharthar inlet channel in action.

Dr A. D. Lewis observed that the Paper had made it obvious that considerable work was still required in order to make the best use of Lake Habbaniyah and the Abu

Dhibbis Depression, and that the latter would have to play a bigger part than the former in future.

153. The remarks, however, in §§ 104–107 presented a quandary. In § 104 it was stated that the Muijarah escape must be enlarged to a capacity of 2,700 cumecs, the consequence being that at first there would be a much larger intake into the Depression than at present; but there seemed to be a fear that evaporation would not be able to prevent the water from rising to a level which would seriously drown the intake, because “there is no escape” back to the river.

154. It must be presumed that this last expression meant that the construction of an adequate escape would be unreasonably expensive. Without pressing for the results of the “studies” referred to in § 106, it might be suggested that great interest would be added to the fascinating problem raised in the Paper if a brief description of the divide which separated the Depression from the river could be given, together with a capacity table for the Depression and a table of the average monthly depth of evaporation at the site.

155. With regard to the suggestion in § 107 that other storage works higher up the river were contemplated, which might help in solving the problem of flood-protection coupled with irrigation, Dr Lewis asked if any exhaustive reconnaissance had been made in this connexion, as had been suggested by him³ in 1945.

Mr F. S. Hardy (Partner, Messrs Binnie, Deacon and Gourley (Baghdad), Consulting Engineers) observed that when a project like the Habbaniyah was first envisaged and designed it was difficult to foresee how the pattern of irrigation requirements might develop. The Paper provided an instructive illustration of the changes in purpose of a river control project which occurred in the course of time as new factors emerged. Flood control requirements were bound to alter in consequence of changes in river regime, resulting from the very fact that control had been imposed and, in the case of the Euphrates below Kifl, from the fact that the river system was still building up its delta. The changes in river regime largely depended upon methods of operating the flood control. The operating rules covered the general case but every flood posed its own particular problems which had to be dealt with according to the judgement of the controlling authority.

157. It was therefore necessary that, as far as possible, river-control projects should be designed to allow for changes in criteria of purpose and operation. The Dhibban Outlet Channel was an instance. The pre-war design provided (§ 31) for a capacity of 187 cumecs, whereas by the time, in 1952, of the first use of the outlet it had been found more beneficial to irrigation requirements (as noted in § 98) to run a discharge of 300 cumecs for short period. The consultants’ designs had provided wide berms at ground level on the channel between the regulator and the river, so that although some scouring of channel sides had occurred it was of no significance. The release pattern of 1952 had been continued in most subsequent years with no ill-effects on the channel and great benefit to agriculture.

158. Mr Hardy suggested that the third of the main considerations listed in § 19, for designing and operating the Habbaniyah Scheme, contained a questionable proposition, namely, “in considering the storage of water for irrigation it is essential that the supply should be constant each year”. Operating rule (h) in § 20 followed in consequence and would result in supply of storage water being limited to the quantity which could be assured even in years of very unfavourable river flows. Irrigation storage schemes were almost invariably most beneficial when operated on the basis of the yield which was obtainable in a period more favourable than the worst. A shortage from the normal yield then occurred in a very unfavourable period. The tolerable shortage varied according to the particular circumstances—20% was not unusual. Acceptance of a tolerable shortage in bad periods resulted in less wastage of water in good periods and a higher average out-turn of irrigated crops. For this reason and with all respect to the

memory of that great irrigation engineer, J. D. Atkinson, under whom Mr Hardy had had the privilege of serving, his operating rule (*h*) had not been enforced.

159. Another way in which operation of the scheme had departed from the rules proposed was in the rate at which flood-water had been diverted through the Warrar Inlet Channel. To reduce siltation of the channel it had been found necessary to run discharges of less than 700 or 800 cumecs as seldom as possible. Furthermore, at first opening of the regulator it was always necessary to run a large discharge to scour away the large quantity of silt which had settled in the reach between the river and the regulator. From that aspect it would have avoided some difficulties in operation if the Inlet Regulator and Ramadi Barrage had been in one line. The nose end at the bifurcation between inlet channel and river might also then have required less maintenance, since there could have been control on cross-flows by suitable gate operation. Control of entry of silt would likewise have been more available. However, separation of the two control structures did facilitate construction.

160. In § 105 reference was made to the large discharges passed down the Mularah Escape Regulator and Channel in excess of the design discharges. In the 1954 flood the alternative would have been very serious flood damage on the Euphrates, for the river flow in excess of the tolerable discharge of 2,600 cumecs amounted to a volume of 5.4×10^9 cu. m, with a peak discharge of 4,730 cumecs. The 1940 flood, referred to in § 18 as one of the two design floods, had a volume of only 3.2×10^9 cu. m in excess of the discharge of 2,600 cumecs, with a peak discharge of 4,430 cumecs. The Habbaniyah Scheme had been designed for recorded floods for reasons of economy and it was therefore inevitable that at some time it would be over-taxed.

161. The Authors had given approximate figures for the benefits which had accrued from the Habbaniyah Scheme in 1952. In subsequent years the benefits had rarely been less and in some years perhaps even more than in 1952. Mr Hardy endorsed the Authors' statement in § 103 that the advantage from flood control had been more important, though apparently less in financial benefit, than the advantage of irrigation storage. For the same reasons which the Authors had given with regard to the Habbaniyah Scheme, the benefit of the Wadi Tharthar flood control scheme on the Tigris, for which the Authors' firm were also the Consultants, had been even greater and equally inestimable.

162. A notable feature of the Habbaniyah Scheme was the low cost of its construction. In this instance, the system of cost plus a fixed percentage, on which much of the work was carried out, certainly showed up well. The high quality of the Resident Engineer was undoubtedly a principal factor.

Mr A. R. Thomas (Consulting Engineer) asked the reasons for siting Ramadi Barrage and Warrar Regulator each some distance downstream from the point of diversion. In the case of barrages for diversion of water into irrigation canals it was usual to locate the canal regulator adjacent to the barrage so that approach flow could be controlled by operation of barrage or undersluice gates and the channel could be scoured when desired by opening the undersluices. It was recognized that the requirements differed in the two cases. Irrigation canals generally carried a relatively small discharge throughout most of the year, whereas in the present case a large proportion of the flow was to be diverted during floods. The question of proportionate distribution of sediment load was a major consideration and the location of the offtake on the outside of a sharp bend would reduce the quantity of sediment entering the inlet channel. No doubt measures would be taken to ensure that the river adhered to its present course, so that the flow pattern at the offtake would not change.

164. Once the position of offtake had been decided, it appeared that the most efficient control would have been obtained by locating the barrage immediately downstream of the bend, but the structure would then have been exposed to severe scouring action, owing to the sharply curved approach flow. The site chosen was safer in this respect. The same reason may have led to the siting of the regulator also at some distance from the point of diversion, though there must in consequence be a silt problem

in the approach channel to the regulator with no means of scouring except into the inlet channel downstream. For this reason a short approach channel was preferable to a long one.

165. Had silt deposited in the approach channel; if so, had this occurred mainly when the regulator was closed or open? Was it fine silt (from suspension) or sand (from bed flow)? Had it been possible to scour a channel rapidly in advance of a flood by operation of the regulator gates?

166. There must be other sediment problems, in particular in the inlet channel below the regulator, in the lake, and also in the river, which would now have to carry an increased load. It was noted (§ 98) that water was taken in "gulps" through the Dhibban outlet and that this had a beneficial scouring effect in the canals. Large discharges had a greater load-carrying capacity per unit volume than had small discharges. During low and moderate floods, rather than pass steady flows simultaneously down the inlet channel and river it might be beneficial to operate the gates so that the flows would be intermittent, alternating between inlet channel and river, using the channel to its maximum capacity, in order to maintain that capacity and reduce accretion in the river.

167. Some accretion in the river downstream of the barrage, however, appeared to be inevitable. In the first few years this might not be noticed but in the course of time the river might be expected to adopt a channel in accord with its new regime, with a smaller waterway, higher specific levels, and a lower safe maximum flood. It would enhance the value of the Paper if data of high floods in the past could be provided with an estimation of the probable frequency of floods exceeding the safe capacity of both channels in the future, which could be compared with the frequency of floods exceeding the capacity of the river alone in the past.

168. In the framing of operational rules it was necessary to consider both rate and volume of discharge on a frequency basis. There was also the question of over-year storage for irrigation, carrying over water from wet years for use during dry years. The snow survey recently instituted by the Hydrological Survey of Iraq in the neighbouring Tigris catchment should prove of benefit in estimations of summer river-flows in time for the control of diversion operations in the latter part of the flood season.

169. The figures of costs and benefits provided a striking justification for this scheme, which would evidently pay for itself by storage for irrigation, quite apart from the considerable flood-control benefits.

Mr N. J. Cochrane (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) observed that when introducing the Paper the Authors had indicated a value of nearly 1.75 m for the observed annual evaporation from Lake Habbaniyah, which agreed with a value of 1.8 m quoted in the Haigh Report.²

171. Blaney had published much information on evaporation from desert lakes in the United States of America and reference might be made to his observed figure of 79.46 in/year from Silver Lake⁴ in the Mojave Desert in California. At Silver Lake the mean annual temperature was 70°F, the mean annual humidity 55%, and the mean wind speed at 10 m about 7 m.p.h. At Habbaniyah the equivalent data were 73°F, 43%, and 7.7 m.p.h. which, indicating a hotter, drier, and more windy climate, should result in an appreciably greater evaporation than at Silver Lake.

172. Mr Cochrane had propounded^{5, 6} an empirical evaporation formula in the form:

$$E_c = \frac{T^2}{100} \sqrt[3]{\frac{U+3}{20H_r}} \left(\frac{60}{H_r T} \right)^{0.8}$$

where E_c denoted the calculated annual evaporation in inches.

T " " mean annual temperature in degrees Fahrenheit.

U " " mean annual wind speed in m.p.h. at 10 m.

H_r " " mean annual relative humidity.

This formula indicated an evaporation of 95 in. or 2.42 m at Habbaniyah. It would be

helpful if the Authors would describe in detail the evaporation measurements which were actually made at Habbaniyah.

Mr A. R. Porter also referred to the Authors' value 1.75 m for the annual evaporation loss and to the figure of 1.2 m (60%) evaporation during the 4 months May to August. He also noted the close agreement with the value of 1.8 m given in the Haigh Report.² The monthly distribution, expressed as a percentage of the annual loss, was also given in the Haigh Report, the percentages and the derived monthly losses being:

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
% of total	1.5	2.0	3.5	5.8	10.9	17.0	20.4	17.0	10.9	6.9	2.6	1.5
Loss; cm	2.7	3.6	6.1	10.4	19.7	30.6	36.7	30.6	19.7	12.5	4.7	2.7

The loss shown here during the four months May to August is 117.6 cms, or 65% of the total for the year.

174. Mr Porter was surprised that the observed losses, particularly those for the three months December to February, should be so low. From the nature of climatic conditions in the area of the lake he would expect the annual evaporation losses to be much more than 2 m.

175. The Haigh Report² stated that attempts had been made to apply various formulae based on temperature, wind velocity, humidity, etc., but the results obtained had been inconsistent and high (high, presumably, compared with the observed figures).

176. The most recent approach to the problem of the estimation of open-water evaporation from associated meteorological factors was that of Kohler and his colleagues of the United States Weather Bureau.⁷ This had followed upon experiments carried out at Lake Hefner,⁸ in Oklahoma, where, together with a water-budget measurement of lake evaporation, observations had also been made on a number of evaporation pans, including the U.S.A. Class A pan, and related to pan-water-surface temperature, air temperature, dew-point, wind-speed, and solar radiation. This approach was a quasi-empirical energy-budget method which, by employing the results of such observations, made it possible at Hefner and at other bodies of water in the United States, to relate lake evaporation to evaporation from representative pans.

177. Kohler had also shown that, in the absence of actual pans, the evaporation from a "theoretical" pan could be reliably estimated from the pertinent meteorological factors and that this could then be adjusted by use of the same factors to give lake evaporation.

178. Using Kohler's method, Mr Porter had made an estimate of the mean monthly and annual evaporation from Lake Habbaniyah over the period covered by existing meteorological records. These, made at the Royal Air Force station near the Lake, covered the 18 years 1937 to 1954, which would appear to embrace the period of the observations mentioned in the Haigh Report,² and should be representative of actual conditions on the Lake. The records were of air temperature, relative humidity, and wind-speed, but not solar radiation, and the mean monthly variation is shown in Fig. 19.

179. In this method, if no figures were available for solar radiation, then pan-water-surface temperatures were necessary. At Habbaniyah, so far as Mr Porter knew, there were no pans, but the results of observations made on a large number of pans in West Africa, in both desert and humid climates, showed that the difference between air and pan temperature could be estimated from the meteorological factors which were available at Habbaniyah. His estimates of evaporation from a "theoretical" Class A pan and of the derived lake evaporation at Habbaniyah, expressed in centimetres as monthly means for the period 1937 to 1954, were:

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Pan	11	15	20	26	40	49	61	54	37	25	15	12	365
Lake	9	11	14	18	26	31	38	34	24	17	11	9	242

These figures, together with the figures derived for the percentage distribution given in the Haigh Report, had, for comparison with the available meteorological figures, been

plotted on Fig. 19. The monthly "pan factor" varied from 0.82 in January to 0.62 in July, the annual figure being 0.66. The estimated loss during the four months May to August was 129 cms, or about 53% of the yearly total.

180. The Haigh Report referred to high and inconsistent results having been obtained from the use of formulae. By insertion of the mean meteorological elements for 1937-54 in Meyer's formula, which was "said" to give results within 20%, Mr Porter obtained an annual loss of 264 cm.

181. The yearly loss, as estimated by Kohler's method, was about one-third higher than the observed figure. It would be seen from Fig. 19 that the discrepancy was greatest for the months of February to April and smallest in June to July. Whether this estimate was valid or not, there were two points about the observed figures which led Mr Porter to doubt them. The first was the low observed evaporation for the winter months,

FIG. 19

particularly December and January, the total for which was only 5.4 cm. At Lake Hefner, in approximately the same latitude, in 2 months with the same mean air temperature and humidity as at Habbaniyah in December and January, but with a somewhat higher wind-speed, the evaporation was 24 cm. The difference in wind-speed would reduce this to the equivalent of 16 cm at Habbaniyah.

182. The second anomaly, more obvious, concerned the observed evaporation for June, July, and August. A comparison between the relevant meteorological factors for these three months would show that the August evaporation must be approximately midway between those of June and July, and about 10% greater than that of June. Added to this, the temperature of the water must be higher in August than in June, increasing the evaporation rate even more. Yet the observed evaporation for the two months was said to be the same figure.

183. In the estimate based on Kohler's method no adjustment had been made for energy advected into the lake, since none of the factors necessary to assess it were available. Mr Porter would expect, in years when the Euphrates flood was allowed to flow into the lake and later escape, that the seasonal distribution of evaporation would

be affected, but would not suppose that this could account for any great difference between the observed and estimated annual figures.

184. As he had noted, the difference between the observed and estimated figures was least in June and July. This occurred just after the peak of the Euphrates flood when, if, by breaching, the river had been allowed to flow into the lake, river and lake levels were most nearly equal. The difference was greatest when the lake level was at its lowest, between October and March. This suggested that, if the estimated evaporation figures were realistic, then the difference between the two might be accounted for by unmeasured inflow by seepage from the river and surrounding water-table into the lake. Had this possibility ever been considered and had any investigations, such as the sinking of observation wells, been made to this end?

185. If, on the other hand, it was certain that there could be no inflow, at present unmeasured, into the lake, or if there was that it could be reliably estimated, then it would seem that the control now established on Lake Habbaniyah would provide a great opportunity to follow up the excellent work carried out by the U.S. Weather Bureau at Lake Hefner. So far, apart from this and similar experiments in the United States, little had been done to put the estimation of open-water evaporation on a scientific basis, and the need for it was apparent.

186. Visible flow into and out of the lake could now be measured at the regulators. What would be further required would be the establishment of an evaporation station on the shores of the lake, or better still two, one upward and one downward in the direction of prevailing winds. They should be equipped with Class A pans, with attached anemometer for recording wind at pan-height, and observations should be made of air and pan-water temperatures, dew-point, rainfall, wind, and solar radiation. Records should also be kept of river and lake-water temperatures.

The Authors, in reply, thanked Mr Allard for his contribution about the early history of the scheme and Mr Ionides for an account of the latest study of the whole river system of Iraq, both of which enhanced the scope of the Paper.

188. Mr Brown had explained the difficulties the contractors had experienced in breaking up the ground. That together with the difficulty in obtaining spare parts arising from the world situation in excavating plant in 1947-48, supplied the answer to Mr Allard's inquiry of what hampered the work on the cut from the Lake to Dhibban.

189. The salinity of the water in Lake Habbaniyah varied from 120 to 350 parts per 100,000, 350 parts being measured in 1932; but it might have increased considerably during 1933-36 when no flood-water was admitted to the Lake. In this connexion it was of interest that the bilharzia germ, so prevalent in the irrigated districts, had been unable to exist in the Lake in 1950, so that the Authorities had permitted swimming in the Air Force Cantonment at Habbaniyah. In 1955, owing to the annual filling and emptying of the Lake the brackishness was so far reduced that the appropriate Authorities were then considering prohibiting bathing in the Lake.

190. The position of the Abu Dhibbis Depression, mentioned in §§ 4 and 106, relative to the Habbaniyah Lake and the River Euphrates, was shown in Fig. 19a. The Razzaza Dike at the south-east corner of the Depression protecting the town of Karbala had a crest level of +33.00 m. The salinity of the Depression varied. In the spring of 1955 the salt content was 900 parts per 100,000 when the water level was 26.90. It was agreed that the water was unsuitable for returning to the river without very considerable dilution.

191. In § 126 Mr Addison had referred to the effectiveness of the lip weir of the Mularah Regulator. This had no connexion with the scouring of the Mularah Escape Channel, which was in fact caused by the too steep gradient of the channel. Reverse heads of 2.50 m at the Warrar Regulator and 3.80 m at the Dhibban Regulator had created no difficulties in either the design or working.

192. The Authors agreed with Mr Hardy that the departures and variations made in the sequence of operations originally worked out were justified in the light of operational conditions. They had little doubt that although Mr Atkinson gave the flood

relief aspect of the scheme priority he would not have disagreed with Mr Hardy's reasoning and opinions on the acceptance of tolerable shortages during certain years, which would provide a higher over-all yield. No doubt Mr Atkinson meant his rules to apply only until circumstances and experience called for modifications.

193. Mr Bennell had referred to the design of the floor against uplift pressure and had

FIG. 19a

asked whether a drainage blanket such as that used in the United States had been considered. On a permeable foundation it was not suitable. The more recent structures were designed on the analysis of the exit gradient as propounded by Khosla⁹.

194. The object of the lip weir at the end of the apron of the Warrar regulator, also mentioned by Mr Bennell, was not to ensure that a standing wave always formed on the apron. Its function was to ensure that under conditions when the standing wave would not form (small gate openings at high head with the downstream dry) the jet would be thrown well clear of the apron. A stilling pond was not included at the Warrar regulator, but for greater discharges one had been adopted in the re-design of the Mujarah Regulator.

195. In reply to Mr Bennell's inquiry about the deposit of the sediment, attempts had been made to estimate how many years would elapse before the dead storage of the Lake became full of sediment; a loss of 20 to 25% capacity in 100 years was thought possible. So far as the Authors were aware no measurements had been taken to ascertain the quantity of silt deposited. However, a delta had formed and was visible at the end of the inlet channel when the water was low in the Lake.

196. The Authors agreed with Mr Allen that flood peaks appreciably greater than

any so far recorded might occur. The inlet regulator had been designed to allow for a 20% increase when the Lake level was raised to level 51.00 m. Much depended upon whether the inlet channel below the regulator would scour sufficiently to take the discharge. The Haigh Commission and the Authors considered that it might. Mr Allard had emphasized the short period, 17 years, during which records were available. In 1946 the information available was not enough to estimate with any degree of accuracy the maximum long-term flood flow, or the probable frequency of flood exceeding the safe capacity of the two channels suggested by Mr Allen (§§ 138) and Mr Thomas (§ 167).

197. In reply to Mr Allen's inquiry of the extent of scour in the Warrar Inlet Channel, the Authors were unable to give precise figures; but scour had taken place where the channel narrowed and the capacity had increased. At that time, works to limit scour were not needed.

198. Mr Allen had referred to the uncertainty of the quantity of water for summer crops. The Authors were unable to deal with that, since on completion of the structures the scheme had been handed over to the Irrigation Directorate. Mr Hardy had referred to the same matter in §§ 157 and 158.

199. Mr Allen had referred to the off-stream and on-stream types of storage reservoir. The off-stream type often involved costly works to let the water in, and out again to the river. It was not often that the one channel could serve both purposes. On the River Euphrates there was no other choice. Of the two types the Authors preferred the on-stream reservoir since it was simpler to operate, could be more effectively controlled, and required less maintenance work—an important factor where maintenance, as usually understood, did not exist.

200. The other works upstream of Ramadi, mentioned in the Paper and referred to by Messrs Allard and Allen, and Dr Lewis, were works for which plans were being prepared by the Government of Turkey. They included a dam at Keban, below the junction of the River Euphrates and its tributary the Murat River, for the purpose of power generation, with a reservoir capacity of 22×10^9 cu. m, and capable of full regulation of the river. The maximum recorded flow at Keban since August 1936 was 6,600 cumecs. A further dam at Halfeti was proposed, lower down the river and some 55 miles, by river, north of the Syrian boundary, it would have a reservoir capacity of 26×10^9 cu. m, also for power regulation. It seemed likely that the dam at Keban would be put in hand within the next few years.

201. Several references had been made to the Abu Dhibbis Depression. The divide between the Depression and the river referred to by Dr Lewis was described on Fig. 19a as High Desert. The capacity of the Depression according to NEDECO was approximately:—

At level 20 m	0.6×10^9 cu. m
„ „ 25 m	3.7×10^9 cu. m
„ „ 30 m	9.4×10^9 cu. m
„ „ 33 m	13.6×10^9 cu. m
„ „ 35 m	16.7×10^9 cu. m
„ „ 40 m	25.2×10^9 cu. m

202. The actual return of water from the Abu Depression to the River, apart from its salinity, was not practicable because the Depression was well below the river level. The water level in the Depression would have to be raised to above +32.00 m to effect this. Dr Lewis was correct in his assumption that to construct an adequate escape would be unreasonably expensive. The Authorities had since decided that the Depression should not be used for storage of water for return to the river, and that the alterations to enlarge the outlet regulator at Mujarah should be postponed.

203. Messrs Cochrane and Porter had referred to the evaporation in Lake Habbaniyah. The figure of 1.75 m given in the Paper, had been taken from measurements made monthly for a number of years and no doubt included some seepage both in and out.

More recently the Netherlands Engineering Consultants had given, by means of the Penman formula, an average of 1.95 m with a distribution as follows:—

	Jan.	Feb.	Mar.	Apr.	May	Jun.
% of total	2.4	4.1	6.3	9.3	12.5	14.1
Loss: cm	4.6	7.9	12.3	18.2	24.3	27.5

	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
% of total	15.3	13.9	9.9	6.9	3.3	1.9
Loss: cm	29.9	27.1	19.4	13.5	6.5	3.8

The Authors thanked Mr Porter for his interesting contribution.

204. Reference had been made by Messrs Hardy and Thomas to the siting of the Warrar Regulator and of the Barrage. The layout of the two structures was based on model tests. One object was to ensure uniform distribution of flow over the length of each of the structures, because the offtake of the Warrar Channel was just downstream of a big bend in the river; they also wanted to prevent trouble like that experienced in 1939 at the Gharraf Intake Regulator at the Kut Barrage, where uneven flow had caused undermining of the whole upstream floor of the regulator. The construction of the Warrar Regulator had been started and completed some time before funds were available and before the construction of the Ramadi Barrage had been authorized.

205. Because the Warrar Regulator had been sited so far downstream of the offtake, a sedimentation basin had been provided upstream of the regulator. The silt deposited in the regulator was easily removed periodically during periods of low water. Mr Thomas had inquired whether silt had been deposited in the approach channel. That was so; fine silt (from suspension) was deposited mainly when the regulator was closed. In § 159, however, Mr Hardy had said that much of the silt was scoured through the regulator into the Lake. Whenever possible, the first 4 days' flood water, if the silt content of the river was exceptionally high, was not diverted into the Lake.

206. Mr Ionides's letter to *The Times*, quoted by Mr Addison, was not a valid criticism of the project, but rather the reverse. Mr Hardy had stated that since 1952 the benefit had rarely been less than it was in that year.

207. The Authors then drew attention to the following misprints in the Paper:—

Figs 3 and 4, pp. 412, 413. The captions and Figure numbers should be interchanged.

Figs 14 and 17, facing p. 425. The captions (not the Figure numbers) should be interchanged.

REFERENCES

2. F. F. Haigh, "The control of the rivers of Iraq and the utilization of their waters". Irrigation Development Commission, Iraq Govt, 1949.
3. E. V. Richards, "The flood problem in Iraq". Correspondence by A. D. Lewis, *J. Instn civ. Engrs*, vol. 24, p. 495 (Oct. Suppl. 1945).
4. H. F. Blaney, "Evaporation study at Silver Lake in the Mojave Desert, California". *Trans Amer. Geophys. Union*, vol. 28 (1957), p. 209.
5. N. J. Cochrane, "Evaporation from lakes and reservoirs". *Wat. Power*, vol. 8 (1956), p. 192.
6. N. J. Cochrane, "Lake Nyasa and the River Shire". *Proc. Instn civ. Engrs*, vol. 8, p. 363 (Dec. 1957).
7. M. A. Kohler, T. J. Nordenson, and W. E. Fox, "Evaporation from lakes and pans". U.S. Dept Commerce, Weather Bur., Res. Pap. No. 38, May 1955.
8. "Water-loss investigations, vol. 1—Lake Hefner studies." U.S. Dept Interior, Geol. Surv. Circ. No. 229, 1952.
9. A. N. Khosla, N. K. Bose, and E. M. Taylor, "Design of weirs on permeable foundations". *Cent. Bd Irrig., Simla, Publ. No. 12*, 1936.