Paper No. 5457.

"The Flood Problem in Iraq."†

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Mr. E. Batchelor observed that at a date not more remote than the Glacial epoch, the Euphrates discharged into the sea near Hit and the Tigris near Samarra. Lower Iraq was the product of the erosion of the catchments of those rivers and of those of the Dyalah, Karkeh, and Karun. Since the time of Alexander the Great the silt brought down by those rivers had added an average of about 3 to 4 square miles per annum to the land at the head of the Persian Gulf. Further, the silting of the marshes along the rivers and the silt deposited by high floods on land adjoining the rivers continued to raise the level of the land throughout Iraq, as it had done in the past. The retention of silt in reservoirs on those rivers would retard the growth of Iraq both horizontally and vertically : and the former growth was of great present value.

The Author had not stated how the "approximate estimates of the maximum peak discharges on the Tigris and the Great and Lesser Zabs" (p. 161) were arrived at. The banks of the Tigris above Baghdad had always been breached at times of high floods, and the discharge in the Tigris above the breaches had not been ascertained at those times. The discharge for the Tigris at Mosul was given as being less than that for the Great Zab at Girdmamik, although the catchment-area was more than three times as large. Those discharges were small fractions of those for equal catchments provided for in India by the Irrigation Department. A rainfall of 6 inches in one day was recorded at Baghdad in February 1894. The hydrograph for the year 1907 showed that there was heavy rainfall on the catchments almost continuously for a period of 50 days. The average annual yield of the catchment above Baghdad exceeded 12 inches for the period 1906–1911. The yield required from the catchment above Girdmamik to give a discharge of 6,500 cumecs for one day was about $1\frac{1}{3}$ inch : and it was almost certain that that had been largely exceeded on many occasions. The reservoir-content equalled a yield from the catchment of $3\frac{1}{2}$ inches. When filled, the reservoir would be of no value for flood-control. It was not easy to follow the method of regulation of the proposed reservoir given on page 163. A diagram showing possible heavy rainfall, a flood hydrograph for that rainfall, and a diagram giving the content of the reservoir throughout the period assumed, would be of

† J. Instn Civ. Engrs, vol. 24 (1944–45), p. 145 (Apr. 1945).

great value. The hydrograph would be a deal more trying than that given for the year 1907.

If a rate of erosion of the catchment of 1 foot in 1,000 years were assumed, a period of 300 years would be required to erode $3\frac{1}{2}$ inches and to silt up the reservoir, even if it were assumed that the whole of the material eroded was in suspension and was retained in the reservoir. There appeared to be no good reason to trouble about silting.

It appeared that the proposed reservoir was not large enough to diminish materially the volume of large floods at Baghdad. However, other methods of dealing with the problem suggested by a perusal of the Paper and other sources might well be of value.

Lieut.-Col. A. R. B. Edgecombe observed that the Author had referred to Iraq as a land devastated by floods, but he was surprised at the smallness of the estimated peak floods. The Author had stated that a peak discharge of 6,000 cumecs (211,800 cusecs) might occur on the river Great Zab, with a catchment-area of 25,900 square kilometres (10,000 square miles). How had he arrived at that figure of 6,000 cumecs? If it was derived from rainfall statistics little reliance could be placed on it. On the Sutlej river in the Punjab attempts to correlate river discharges with observed rainfall had failed. Likewise on the Indus river, in connexion with the Sind-Punjab dispute over the distribution of the waters of that river, such a correlation was unsuccessful.

It would be very unwise to assess the maximum flood of the river Great Zab, with its catchment-area of 10,000 square miles, at less than 19,830 cumecs (700,000 cusecs), which was more than three times as great as the Author's estimate. Col. Edgcombe had arrived at that figure using Sir Claude Inglis's formula $Q = \frac{7000A}{\sqrt{A+4}}$, where Q denoted maximum flood discharge and A the catchment-area, in square miles. That formula applied to fan-shaped and not elongated catchments and the river Great Zab catchment looked fairly fan-shaped.

Evidence was available from all parts of India and Burma, and from the United States, to corroborate Sir Claude's claim that the maximum run-off of a river for dry and wet zones was the same. In the words of Sir Claude, " . . . his formula was intended for fan catchments under conditions when a storm was large enough to cover the whole catchment and lasted long enough to saturate it." The formula fitted Indian data and American data as quoted by Gutmann [1] and by Jarvis.[2] It resembled the " modified Myers " formula, $Q = 10{,}000\sqrt{A}$, and the formula $Q = 6{,}000\sqrt{A}$ for maximum floods based on American data.[3]

[1] Bombay, P. W. D., Technical Paper No. 58, by Inglis and Joglekar.

[2] Annual Report (Technical) of the Central Bureau of Irrigation, Government of India, 1942.

[3] " Hydro Electric Handbook," by Creager and Justin, 1927.

The Author had not mentioned what maximum flood he anticipated at the site of his proposed dam in the Bekhme gorge on the Great Zab river. The catchment-area was 16,800 square kilometres (6,459 square miles), from which a maximum flood of 15,920 cumecs (562,000 cusecs) would be expected. It would be interesting to know what means the Author proposed to employ to get the peak flood past a dam 328 feet high and 984 feet long at the crest.

The Author had mentioned suspended silt loads, but had made no reference to bed loads. How had he estimated the rate of silting of his reservoirs? In the United Provinces the following empirical formula for bed load contribution had been developed,

$$q = 0{\cdot}1591\ QS$$

where q denoted the average annual bed load, in acre-feet, as measured in reservoir deposit; Q the average total annual discharge of the river, in acre-feet; and S the average slope of the river, expressed as a number.

Col. Edgecombe suggested that if the necessary data were not available, the Author should take a ceiling figure of 75 acre-feet of reservoir deposit per 100 square miles of catchment per annum. World data showed that that was unlikely to be exceeded in reservoirs of catchment-areas exceeding 4,000 square miles.

What rates of evaporation did the Author anticipate from depressions?

In discussing the rate of travel of floods, the Author had stated: "The times imply a constant velocity of 7·3 kilometres per hour, but in view of the relative slope of the river this appears unlikely." He might have sufficient data to apply a check on the following lines:—

Sir William Willcocks had recorded the following of the Tigris between Baghdad and Basra:

Width 350 metres;
Slope 1 in 20,000;
Flood discharge 5,500 cubic metres per second;
Velocity 6 kilometres per hour.

Calculating the velocity theoretically, the silt factor (Lacey), from $S = \frac{0{\cdot}000542 f^{\frac{5}{3}}}{Q^{\frac{1}{3}}}$ worked out at 0·8087. Using that silt factor and the above-mentioned discharge in Lacey's formula, $V = 0{\cdot}79371(Qf^2)^{\frac{1}{6}}$ gave $V = 5{\cdot}627$ feet per second $= 6{\cdot}2$ kilometres per hour. Incidentally it was worth noting how well Sir William Willcocks's data fitted Lacey's formula $P = 2{\cdot}668Q^{\frac{1}{2}}$ for the width of the river.[1]

The storage of flood waters in depressions sounded strange to an Irrigation Engineer in India. There the first thing done when introducing a canal system into new country was to link the depressions with surface drains so that after heavy rain the water would not stand in them longer

[1] G. Lacey, "Regime Flow in Incoherent Alluvium", Central Board of Irrigation, India, 1939.

than a week or so. The object was to avoid waterlogging under the dual influence of irrigation and rain water seepage. Had the question of waterlogging been considered by the Author, and if so, what were his conclusions ?

Also, what were the catchment-areas for the cases quoted at the foot of page 161 ?

Irrigation engineers in the United Provinces, India, were always interested in Iraq, which they associated with Sir William Willcocks, who learnt his irrigation in those Provinces.

Mr. A. M. Hamilton observed that the annual floods of the Tigris and Euphrates, and their intensity, affected to some degree practically all undertakings in Iraq—and indeed the whole life of the country.

The Author had done a surprising job in making such a thorough investigation of the course of the Greater Zab, particularly at the unsettled time during the war. Even if, owing to his capture, the Author had not managed to complete his investigations, they formed no mean achievement in such a wilderness of crags and crevasses, and must have involved no little danger to life and limb.

To use the Author's suggested connecting road from the Rowanduz road to the Bekhme dam site, taking off about Batas on the Dasht-i-Harir, or Harir plain, would mean crossing the Pirmum Dagh and Mirowa Dagh passes and was far from being direct and straight to the lowlands. A better route might be that suggested by Mr. Hamilton in a lecture to the Royal Central Asian Society in 1933 [1] in discussing future east-west road arteries of Asia ; a suggested short cut from Mosul to the Rowanduz road was via Bekhme, for in addition to being a good site for a dam it was also possible there to cross the river by a single, instead of a multi-span, bridge. Another possible road line to Bekhme was the very ancient caravan track from Arbil by way of Babachichek, running near the site of the battle of Arbela (331 B.C.).

The route, much used by the Author, to the rear of the Bekhme gorge from the Khalifan valley was surveyed by one of Mr. Hamilton's overseers in 1930 after a careful search had revealed a suitable low pass. That raised the question whether a trunk highway, and not just a construction road, should not be made through the gorge in conjunction with the proposed work on the dam, for it was often found that adherence to a river valley (if possible) gave the best graded line for a road—so a dual purpose might be served.

The Author had expressed doubt whether working on the dam could be sustained all the year round. The climate appeared to be either freezing cold in winter or boiling hot in summer ; but, actually, to work all the year round, even using explosives and machinery affected by temperature, was not so difficult as might appear at first, if the engineer and his personnel were willing to face the loneliness and inconveniences, and had medical

[1] " Construction of the Rowanduz Road," J. Roy. Central Asian Soc., vol. 30.

assistance to deal with the common, but rarely serious, local epidemics of malaria and dysentery. Winter or summer, Mr. Hamilton's work never stopped, in Kurdistan, so long as there was any money to pay the workmen, and he was the first to show that that could be done. His Rowanduz Road Construction Report for the year 1928 included the following entry:—"The experience of the winter work has shown (*a*) all work can be carried on efficiently; (*b*) more labour is available in winter than in summer and is willing to work in any weather if required. This winter the labour has been reduced from 2,000 to 100 men on account of shortage of money, though it is clearly inadvisable to discharge labour that has been trained to the work." In his experience the winter months were often not so cold or so wet as might be anticipated; Table I, p. 494, *post*, extracted from his diary and camp records, showed the mild weather that might occur.

Hydro-electric aspects of the Bekhme dam.—The siting of a dam at Bekhme for hydro-electric and irrigation purposes had several times been advocated by Mr. Hamilton. In the "Baghdad Times" dated 18 August, 1932, he discussed at some length the hydro-electric potentialities of Kurdistan and gave prominence to Bekhme as the best dam position available; hence his efforts to bring it into the Rowanduz road plans even before that time. In a further article dated 29 August, 1932, he discussed inland navigation in Iraq and made proposals assuming controlled water-levels. The value of the Bekhme dam for local irrigation and local industries was also mentioned on page 111 of his book "Road through Kurdistan," published in March 1937.

It would be interesting to have the Author's opinion on the local irrigation, hydro-electric, and inland navigation aspects of the Bekhme project. Such developments would provide peaceful and profitable occupation for the many races and peoples, and development of the resources of the country might at last tranquilize and transform a hitherto rather bloody and turbulent land.

The value of combining as many different engineering objects as possible with the flood-control proposal would be evident when the following factors were considered.

Northern Iraq, embracing that section of Kurdistan, was a peculiarly restive spot and yet one of the highest diplomatic importance to the British Empire. It included the Kirkuk and Mosul oil-fields and supplied the Mediterranean pipeline. Further, it lay not far from Soviet Russia, which embodied kindred branches of the same peoples. The local inhabitants claimed, with some justification, that they had not had from the British the consideration of their territorial and personal rights which were their due. All the factions there tended to be strongly nationalistic, unbound to Southern Iraq except under the pressure of British military and air power, which had enforced that union only with some difficulty during repeated uprisings in the past. Those Northern peoples already laid claim to a greater share of the oil interests than they had received. To form a great

lake flooding a large tract of the little useful flat land in Kurdistan for the sole purpose of benefiting Baghdad and the South, where a different and alien people lived, could not of itself make a very great appeal to the local people and they might even prove to be hostile, whilst British military action, or support of Iraqi action, to force the scheme through would be clearly undesirable. A broader scheme, or better still, a complete programme of complementary schemes, to develop and enrich Kurdistan, in *addition* to safeguarding Baghdad from floods and give a better river regime, would almost certainly win local support, and if it had as a definite object the provision of work and industry for the many still unsettled Assyrians, still another harassing problem might be settled.

A complete Tennessee Valley Authority type of development was, in fact, clearly indicated, and it had long been Mr. Hamilton's conviction that that was one of the best solutions for the country's difficulties.

In Mr. Hamilton's opinion, the engineer ought not to confine himself to reporting merely one technical proposition if others that could be integrated with it also had a bearing on future operation. In any case the Hydro-electric power possibility, with a dam 100 metres high, could be no unimportant one; whilst the human element might make or mar everything.

From the Arab point of view contentment and co-operation with the North was an essential pre-requisite of the whole proposal. Otherwise the dam, instead of being a safeguard to Baghdad, could be a very grave menace to that city.

Mr. Hamilton was aware that the first answer always given when a hydro-electric proposition was put forward for Northern Iraq was " Why not use the oil, in such abundance ? " But if there were two or more sources of wealth in a country, why not use them all ? There was not the slightest doubt that industries could be developed to absorb the power. Some examples of what could be done were given in his articles in the " Baghdad Times " of 1932 and in " Road Through Kurdistan ". Those suggestions were still applicable to-day, and many others could be conceived.

Mr. A. F. Lambert observed that before the war he was on the staff of the Consulting Engineers and had done a good deal of work on the Iraq flood-control projects. He wished to emphasize the paucity of hydrological data, referred to by the Author on page 162, *ante*, and in Appendix III. Not only were the available discharge records nearly all for small discharges, but also different readings often gave very different discharges for similar river-levels; so that in constructing the discharge curves it was necessary to " strike an average " through the points plotted. The higher discharges could be obtained only by extrapolating on those curves, and were thus open to serious error. In fact, flood discharges generally (except at Baghdad) could be little more than intelligent guesses. Had the Author any more accurate information at his disposal ?

With regard to the method of operating Bekhme dam, the time of

TABLE I.—ROWANDUZ ROAD CONSTRUCTION METEOROLOGICAL RECORDS.

Temperature and Rainfall for February 1931, *at Jindian, near Rowanduz*

	Rain or snowfall.		Temperature: °F.	
Date.	Hours.	Inches.	Minimum.	Maximum.
1	—	—	34	62
2	—	—	32	60
3	3	0·10	43	64
4	—	—	30	56
5	—	—	32	55
6	1½	0·80	42	54
7	—	—	39	52
8	—	—	48	56
9	—	—	46	52
10	—	—	50	62
11	—	—	45	56
12	10	1	40	52
13	—	1·5 (snow)	32	46
14	—	0·65 (rain), 1 (snow)	30	42
15	7	0·28 (rain), 1 (snow)	31	58
16	—	—	31	58
17	—	—	30	58
18	—	—	30	58
19	—	—	32	46
20	—	—	40	62
21	—	—	38	64
22	—	—	32	50
23	—	—	28	62
24	—	—	30	58
25	—	—	28	60
26	10	0·58	27	62
27	12	0·80	34	56
28	—	—	28	62
Total	43½	4·21 (rain), 3·5 (snow)	Average 35	57

travel from Bekhme to Baghdad was not stated, but from the map Bekhme appeared to be about 100 kilometres above Eske Kelek. At the assumed rate of travel of 7·3 kilometres per hour that corresponded with about 13 hours' travelling time, which gave a total of 64 + 13 = 77 hours from Bekhme to Baghdad: thus, the Great Zab's contribution to the peak would pass Bekhme 13 hours after the main stream's contribution had passed Paish Khabur. But the time of travel from Altun Kupre to Baghdad was only 58 hours, so that the Lesser Zab's contribution to the peak would pass Altun Kupre 77 — 58 = 19 hours after the Great Zab's contribution had passed Bekhme. In other words, when operating the sluices at Bekhme it would be necessary to anticipate conditions in the Lesser Zab by about 19 hours. The assumed rates of flow were admittedly open to question, but whatever adjustments were made on that account, the time of travel to Baghdad from Altun Kupre was bound to be considerably less than from Bekhme. In view of the large contribution which

the Lesser Zab might make, and the rapidity with which it might rise, would not that seriously affect the efficiency of Bekhme dam ?

The Author had confined his attention to schemes for reducing the total volume of floods by storing excess water ; but were there not other possibilities ? The stretch of the river between the confluence of the Lesser Zab and the beginning of the alluvial plain, which was the ideal region for flood-control works, contained no suitable site for a large dam ; but might not sites be found for small dams or barrages, holding up, say, 8–10 metres of water ? The effect of one such barrage would be negligible ; but if a number were erected in series the cumulative effect of " reservoir lag " would very considerably reduce the peak discharge if the flood were of short duration, and the hydrographs in Appendix II indicated that that was almost invariably the case on the Tigris.

Such a scheme, if feasible, could be made entirely automatic in operation, and would not depend on accurate correlation of the discharges in various tributaries. It would not provide storage for irrigation purposes, since its aim was not to store excess water but to reduce the peak discharge by flattening out the flood hydrograph. But it might be advantageous in the long run to avoid any possibility of conflict between the interests of irrigation and flood control.

Such a scheme might well be impracticable ; but the Author's remarks on hydrological data generally, which confirmed Mr. Lambert's own experience, suggested that it would be desirable to collect more reliable data over the Tigris basin as a whole before concentrating on any particular scheme.

Dr. A. D. Lewis observed that the title of the Paper suggested a wider range than was actually covered, since the greater part was concerned with the problem of reducing the level of floods at Baghdad. Perhaps a useful purpose might have been served by a sketch of an aspect of the flood problem, in which centuries, instead of years, formed the unit of time. Without the longer view it might be overlooked that the delta was constantly growing, that it grew by accretions of silt, of which at least 90 per cent. was transported in flood waters, and that, therefore, every part of the delta would at some periods be flooded and at other periods be protected by bunds.

The rate of change of land surface was probably greater than in most large irrigated areas, because of the relatively high percentage of silt in the flood waters, the restricted shape of the gulf that was being filled, and its lack of ocean currents. A very rough estimate of the present average rate might be that the 300-mile length of the delta was extending upstream and downstream 1 mile, and that the surface was rising $4\frac{1}{2}$ inches in 100 years. At any one time the bulk of the silt was probably being deposited on less than one-eighth of the whole area, where the rise would be at the rate of nearly 3 feet in 100 years, and much more than that in parts (as in the famous 8-foot layer at Ur). It was difficult to conceive any practical

measures which would permanently reduce the quantity of silt that entered the delta, or would increase the quantity passing to the sea.

With the unequal rising of the surface of the land, the river beds and irrigation canals would also rise, and to such an extent that only bunds of impossible size could contain their waters. The whole system of one period would then have to be abandoned and a new system for the ensuing period would have to be built elsewhere. That had been the history of the past and would be of the future. No works of man in the delta could be regarded as truly permanent. Towns would shift with the shifting irrigation. The fate of Baghdad was as certain as that of Babylon, Kutha, Lagash, Nippur, etc., and it had already spent a considerable part of its allotted span. In the past, when the delta was divided into rival kingdoms, the shifting of the scene of irrigation and flooding was often catastrophic. Now it was possible to plan an orderly transition and migration, and that type of planning was of greater importance than planning to perpetuate existing works which were doomed to extinction.

Storage works *in the delta* would obviously have a limited life. The location of storage works in the rivers *above the delta* was the usual practice elsewhere, but a more exhaustive reconnaissance was required to make sure that there really were a number of suitable sites in both rivers, especially if the reservoirs were likely to be misused by allowing silt to accumulate in them. If silt were held in the reservoirs for periods even measured only in months, part of it would be difficult to dislodge. Very careful study would have to be given to the best manner of operating the reservoirs to minimize the threat of siltation. All reasonable methods would probably result in a reduction of extreme flood-levels, but fundamentally the manner should be determined by a long-range programme of irrigation development, on which the prosperity of the country depended. In any case "complete immunity from flooding" *in all parts of the delta* would be impossible, and would certainly not be attained by always working to a fixed maximum level of 34·7 at Baghdad. Flooding would be an essential part of land building; it should be directed so as to form a succession of suitable new areas and channels to take the place of the old without major crises accompanying each change.

The Author should be strongly supported in his plea for a careful survey with very close contouring. An intense study of silt in quantity, transportation, deposition, and compaction should also be undertaken.

Mr. G. E. Meade observed that the Bekhme dam should be built as rapidly as studies could be finished and contractors set to work. It was the only scheme which Iraq could afford during the next 10 years and which would at the same time protect Baghdad, that horribly threatened site which could hardly be worse chosen from all sites in central Iraq. The Caliph who moved house to Samarra was wise.

The Author had shown how the Tharthar scheme would be needed to finish the job and save Baghdad from the fate of Nineveh. With the

Bekhme working, a drawoff of 2,000 cumecs into the Tharthar would be sufficient. Using the Willcocks provisional drawing, that meant a cut of about 80 million cubic metres, fed by a weir close to Samarra holding up 7 metres in summer and 6 metres in flood—about an 8 million pound scheme, or less at the rate earthmoving machines were improving.

With the Tharthar for flood-control and the Bekhme for storage, the two schemes were complementary and each cheapened the other. Without the Bekhme working, the Tharthar cut became excessive; with the Tharthar in prospect, Bekhme would not need to be so high.

The Samarra weir would generate 14,000 horse-power, even in the lowest summer, at a conveniently central point for Iraq. The capital might drift back to Samarra after all. Hardly a building in Baghdad was sufficiently well built to last more than 30 years, or the streets more than 10 years. There was no sewage-disposal scheme whatever, and any future scheme would be very costly. Samarra, with a fine site, hard ground for foundations, cheap power, and on the railway to Europe, offered a wonderful chance for Iraq to succeed, where the Caliphs had failed to persist in a fine scheme.

Mr. A. E. Reid observed that the Author had rendered a great service to Iraq by presenting the Paper. It could scarcely be too often or too insistently stated that the flood problem was by far the greatest that confronted Iraq and that until it had been solved no major development of the country could take place.

To place the problem in its true perspective, the best introduction would be for the observer to travel by aeroplane over a stretch of country including North Africa, Iraq, South Persia, and North India. A traveller going from the United Kingdom to, say, Karachi could be forgiven for supposing that the world was made up for the most part of sea and desert, with tiny pockets of cultivated land at infrequent intervals. Everywhere the high ground was being washed into the sea at a rapid rate and in most regions the desert was advancing. Everywhere the great enemy was the desert, and it had to be halted and then driven back.

In the particular case of Iraq, several ancient civilizations had been engulfed by sand or silt or both, and the present civilization would suffer a similar fate unless control were established and maintained.

The Author had done well to stress the importance of controlling the floods in the Tigris as a first step. Those people who would have to fight the desert in the future would need secure bases from which to work, and those bases would have to be along the banks of the rivers. They should not be subjected to perpetual risk of inundation by flood waters.

The Author had made out a good case for the establishment of a dam in the Bekhme gorge for the purpose of eliminating, or nearly eliminating, all risk of flooding in the Central Region, and there could be little doubt that he was right in stressing that it was as a flood control project only that the Bekhme dam should be regarded in the first place. The secondary

value of the dam in connexion with irrigation water was of small importance at the present time.

The natural steps in the improvement of living conditions in Iraq would appear to be :

1. The control of Tigris floods by a dam at Bekhme gorge ;
2. The planting of trees in the proper regions in the hills and their careful maintenance.
3. The disposal of river silt.
4. The provision of water for irrigation.

The Tigris was heavily charged with silt for six or seven months per annum. How much of that silt found its way on to the land, where it was immensely valuable in reducing the salinity of the ground ? Was it correct that the river-bed in the delta reach was rising more rapidly than the land adjacent to it ?

It was known that during a typical Tigris flood less than 20 per cent. of the water passing Baghdad travelled as far as Basrah.

Could the Author state what happened to the silt ? What was the proportion of silt brought down by the Greater Zab and what effect would a dam in the Bekhme gorge have upon it ?

It was possible for Iraq to make for itself a very prosperous future, but there was much to do. Prosperity would not come of itself.

Flood-control and afforestation were the immediate objectives. Disposal of silt and water for irrigation were more distant targets ; but distant only in the sense that they took precedence naturally after flood control and afforestation—not in front of them.

Mr. B. D. Richards observed that, whilst touching on the flood problems of the Euphrates, the Author had dealt more particularly with the greater ones of the Tigris which had been the special subject of his investigation. He had indicated that the area affected by floods on the Tigris extended as far as Beled, 130 kilometres above Baghdad. That city was under constant menace from the floods and by its rapid growth on both banks had caused a bottleneck in the river at that point. The relief of that menace to the city appeared to be the most urgent flood problem awaiting solution, and Baghdad might be considered the point of concentration of the flood. On page 153 the Author had given conclusive reasons why flood-control should be effected by storage rather than by the alternative method of river improvement, and it would be noted that all relief works constructed or projected in the past had followed on the lines of storage in artificial basins or natural depressions adjoining the main river.

The proposed scheme was a departure from all previous schemes or proposals in that the flood-storage basins were to be created, not on the main river, but on two of the principal tributaries, the Great Zab and the Lesser Zab. It was more usual to locate the basins as near as possible to the point of concentration of the flood for the following reasons :—

1. Control of the whole catchment was obtained.
2. The effect of time-lag was reduced.
3. The risk was eliminated of major floods occurring from the concentration of the rainfall on the catchment below the basin.

With regard to the first point, the Author's figures showed that the proportion of the flood at Baghdad derived from those two tributaries was such that control of them would afford adequate relief at Baghdad. The difficulty arising from the time-lag when the basin was far upstream could be met by suitable methods of communication and operation. The third point, which might be of great importance in some catchments, was not so in that case, as the heavier floods at Baghdad were caused by heavy rains and the melting of snow in the mountainous country of the headwaters of the main river and its principal tributaries. The possibility of controlling the floods at Baghdad by the storage dam at Bekhme and a further dam on the Lesser Zab therefore appeared to be established. On the other hand, the Author's detailed investigation of all possible storage sites on or adjacent to the main river, showed that they were, for various reasons, inadequate or impracticable.

The location of the storage basins so far upstream had the great advantage that the floods were virtually " nipped in the bud " and a much greater length of river was afforded relief from high floods, inundation, and erosion.

Mr. Richards considered that the Author's summary was of great importance in placing flood-control and irrigation in Iraq in the proper perspective. Flood-control was the first essential. The flood-control storage would be helpful to irrigation and, conversely, irrigation storage would tend to alleviate to some extent flood conditions. The works constructed primarily for flood-control should, however, be utilized for that purpose, and any utilization for irrigation should be consistent with the attainment of that purpose.

Mr. V. J. Sevian observed that the Author's statement that the " Habbaniya project when completed will provide full (p. 148) and safe (p. 165) control on the Euphrates floods " was rather optimistic. The " Gali Bekhme dam project " had been advanced as a solution by maintaining the peak of the flood passing Baghdad, not above 34·70 (5,300 cumecs). The maximum discharge was nearly 10,000 cumecs (1941), corresponding with a probable level of about 37·00, if the bunds upstream from Baghdad had not deliberately been breached. The dam, when completed, would create a reservoir of from 1·25 milliard to 1·50 milliard cubic metres, controlling a basin of 16,800 square kilometres out of a total of 120,000 square kilometres for the Tigris above Baghdad.

The annual water-supply of the Tigris at Baghdad fluctuated between 15 milliard (1930) and 56 milliard cubic metres (1940), the mean being 37 milliards. The Greater Zab at Girdmamikh (about 70 kilometres below the site of the proposed dam), contributed about 25 per cent. of the

total. It seemed obvious that the capacity of the proposed reservoir (1·50 milliard cubic metres at its ultimate stage, or 4 per cent. of the total mean yearly supplies of the Tigris), was rather too small to cope effectively with a serious flood (p. 163), particularly when under such conditions the supply of the main stem of the Tigris at Mosul attained the maximum allowed to pass Baghdad. Allowances should invariably be made for the extra supplies from the Greater Zab and for the full supplies of both the Lesser Zab and the Adhaim (the three main tributaries of the Tigris between Mosul and Baghdad), for, such consideration might show that the additional works involved to overcome the said allowances were as expensive as, if not more than, the main project.

Filling the reservoir under a strict operative programme could not be expected to provide immunity from floods. The execution of the dam would not remove the difficulties which would continue in the Tigris basin. The great distance between the site of the dam and Baghdad (560 kilometres) rendered the operation difficult and delicate, particularly when control was needed for a few days. Allowance had to be made also for the conditions created by the inflow of part of the Greater Zab ; the whole supply of the Lesser Zab (about 3,500 cumecs maximum) ; the incidence of a rise of the Adhaim (maximum 1,000 cumecs) which could add about 0·50 metre to the level of the Tigris in flood at Baghdad ; and the uncertainty of the unstable régime of the Tigris at Baghdad during the high stage of the river when the relation of discharges to gauges varying considerably had not yet thoroughly been investigated. Moreover, the danger of floods for the basin of the Tigris from the confluence of the Diyalah (31 kilometres downstream from Baghdad) to Qurnah would remain as in past years, although alleviated for Baghdad city and eased partly as far down as Kut only. The possibilities for a stable development of definite areas of arid lands would continue to remain remote.

Ten years had lapsed since the proposal for reservoirs was made with a view to developing the huge arid lands south of the Hamrin (about 7,500,000 acres) and thus, as a direct consequence, relieving the Tigris basin from any danger of floods. Several years would have to be added before completing the Bekhme project, and yet the results to be obtained would not eliminate the floods and would not bring prosperity to the present deserts, since the great part of the water resources of the country would continue, as in past years, to go waste.

With regard to the Author's statement that " the great possibilities of the country cannot be fully developed until the constant menace of flooding is removed," Mr. Sevian considered that the contribution of the Bekhme reservoir was far from removing the menace and did not give ample regular supplies for any consideration for a definite programme for serious developments.

Mr. D. M. Whitehouse observed that when he was employed in building the Kardah Mirriam floating bridge. situated 3 miles downstream from

the new Maude bridge in the centre of Baghdad City, he was in constant touch with the Irrigation Department and the Chief Engineer of Bridges to the Iraq Government. Owing to unfortunate changes in design and classification, the original scheme to complete the bridge before the autumn rise could not be carried out and, as a result, the most intricate part of the whole project occurred simultaneously with the rise and flood.

The gauging stations at Mosul, Eske Kelek, and Baiji, mentioned by the Author, were of the utmost value, and twice daily readings were phoned through to the Irrigation department and forwarded to the Author. Three days were allowed for Tigris rises to reach and affect the work at Baghdad, approximately 2½ days for the Eske Kelek rises, and 2 days for Baiji—the Lesser Zab readings, recorded at Alton Kupre, not being taken into consideration. Another station situated on the Dyalah near the Tigris-Dyalah junction and controlled, Mr. Whitehouse believed, by the civil contractors who were rebuilding the Lancashire bridge, provided intermittent readings when requested.

It was noted that during high-water periods at Baghdad, an extra metre or so was added to that level by the " banking up " effect of that water, which joined the Tigris about 10 miles downstream. That rarely occurred at high-water time, but was common during the two months prior to that, namely, October and November.

In common with anti-erosion measures on the Tigris, experiments were carried out with sandbagging, broken concrete slabs from 1 foot to 2 feet in diameter, and brushwood fascines.

The first was found to be useless in any current exceeding 4 miles per hour, and was swilled away or burst owing to the exceptionally silt-suspended nature of the water. Concrete slabs were useless when used on the outside of a bend where they received full-velocity flow. Brushwood fascines were by far the most successful, and, although expensive through necessity of annual replacement, were the only solution for the outside as well as the inside of bends. The method of construction was as follows.

The bank was first cut away to a regular 60-degree slope, and then terraced at 6-foot vertical intervals, the depth of terrace being about 6 feet. Brushwood bundles were obtained from the Kurdistan area and transported by barges towed and paddled down river. After laying, soil was replaced on the terrace, leaving approximately 1 foot of fascine protruding.

It might be of interest to record the appearance of the Tigris during flood period. In March 1943, a surface velocity of 8 knots was recorded, and Mr. Whitehouse believed that the 1,100-foot wide river did on occasions attain a speed of 10 knots. On the " pool " below the Maude bridge waves of up to 3 feet in magnitude could be whipped up by a strong south wind, making the rowing-boat ferries hazardous—incidentally, he had seen Europeans ill while crossing.

The Author, in reply, expressed his thanks for the useful suggestions and comments made by the several contributors, and observed that the

chief points raised in the discussion appeared to be on the subjects of silt, the magnitude of the flood peaks, and the size of the proposed reservoir.

Mr. Batchelor had suggested that the construction of the reservoir might unfavourably affect the formation of the delta by holding back the silt which would normally go to extend the land out to sea : but the Author thought that that would not be the case, as the silt-content of the Great Zab was far less than that of the Tigris. Unfortunately the silt observations made on the Great Zab were not extensive enough to warrant their inclusion in the Paper. In view of the nature of the catchment, the Author considered that silting-up of the reservoir should not be a serious danger, but he had emphasized the desirability of continuing the observations and collecting as much data as possible.

The question raised by Mr. Reid as to where all the silt went was answered by the bar at the mouth of the river. There were also large deposits at the points where the river breached its banks. As an illustration of that, it might be mentioned that during the 1937 flood a small breach occurred just downstream of Baghdad and fresh silt deposits up to 6 inches in thickness were observed when the water fell.

With regard to the relative smallness of the flood peaks, there were, unfortunately, no rain-gauges on the Great Zab catchment and very few elsewhere. Flood discharges, however, had not been obtained by rainfall statistics, but by actual observations. Colonel Edgecombe had mentioned the discharge which might be expected on the Great Zab as obtained by Sir Claude Inglis's formula, but the Author believed that that formula applied to Indian catchments subject to monsoon rainfall, a condition not obtaining on the Great Zab catchment, where floods were caused by the melting of the snows. In that connexion reference might be made to the many useful formulas on floods from catchments given in the book by Mr. B. D. Richards, M. Inst. C.E., on " Flood Estimation and Control." As stated on p. 162, *ante*, hydraulic data were not nearly so full as might be desired, and the importance of collecting as much as possible before final designs were prepared had been stressed by the Author. The floods on the Great Zab, and to a lesser extent on the other rivers, were violent but of short duration and it was unlikely that the peak levels were maintained for long. The importance of the use of automatic water-level recorders was therefore evident.

Colonel Edgecombe had remarked on what was, to India, the unusual practice of storage of flood waters in depressions. That was, the Author believed, first done by the Babylonians. The depressions examined in the Paper were all, with the exception of the Aqqar Quf, in remote parts of the desert and they dried up in the early summer. The Wadi Tharthar depression, the lowest part of which was below sea-level, was covered with salt in the summer, as was the Sharia depression.

Mr. Hamilton's remarks as to the site of the approach road were particularly interesting, as he had a very intimate knowledge of that part

of Kurdistan. The Author had read Mr. Hamilton's book " Road through Kurdistan " while he was touring the Great Zab basin. The approach road proposed by the Author was not ideal, as it included the crossing of the Mirowa and Pirmum Dagh passes on the existing Rowanduz road, but the site was chosen as it afforded the shortest length of new approach road to the dam site from an existing all-weather road. Mr. Hamilton's suggested route would be better, as it avoided the passes, but it would involve the construction of a much greater length of new road. Approaches from Aqra and from near Khalifan were also examined, but it was decided that that along the south side of the Berat Dagh was the best and the Author was glad to learn that that road had now been made. It was his hope that the extension of the road up the gorge would also be made a permanent one, that use would be made of the dam to cross the river, and that the road would eventually link up with Bille and Amadia in one direction and with Aqra and Mosul in the other.

He thought that Mr. Hamilton had misunderstood his remarks as to winter working. In making them he was referring to survey work only and it would, of course, be necessary to work twelve months a year when construction was started.

The use of the Bekhme dam for hydro-electric power was suggested, but only on a small scale, in the Paper. Whilst the dam could be used for such purposes, its primary object of flood control would be prejudiced thereby if large development was attempted. Many sites for hydro-electric power existed in Kurdistan and might well be developed if it were found that they could compete with the cheap oil. The Author was in full agreement with Mr. Hamilton as to the undesirability of constructing the Bekhme dam solely for the benefit of Lower Iraq, and he suggested that part of the stored water could be used for local irrigation, if suitable areas were available. Mr. Hamilton's suggested dam at the lower end of the Bekhme Gorge (see p. 111 of his book) would serve for that local irrigation and for the development of local hydro-electric power, but the site would be quite unsuitable for flood control or storage owing to the small capacity of the gorge.

The possibility of constructing a number of small retaining reservoirs along the Tigris below the confluence of the Lower Zab had been suggested by Mr. Lambert. That was examined by the Author, but it was found that there were not a sufficient number of suitable sites. It was unfortunate that the Fatah Gorge dam site proposed by Mr. Sevian some years ago had been found to be geologically unsuitable for a high dam, as it would have been an ideal site, situated, as it was, below the confluence of the main tributaries.

The Author could not agree with Mr. Meade's suggestion that the Tharthar scheme would be needed to complete the flood control of the Tigris if the dams proposed in the Paper on the Lesser Zab and the Diyalah were constructed. The advantage of those dams was that the water

stored would be available for subsequent use, whereas in the case of the Tharthar scheme the stored water would all be lost owing to the low level of the depression. The Author believed that the cost of the canal to the depression and that of the barrage across the Tigris would still be excessive.

The size or capacity of the proposed reservoir at Bekhme had been questioned by some contributors. With the method of operation proposed it had been found, however, that the capacity of $1\frac{1}{2}$ milliard cubic metres would be adequate. By that method of operation the peak of the flood was stored and there would be no question of having to pass it at the dam. Mr. Lambert had raised the interesting question as to the time of travel from Altun Kupre to Baghdad. In the operation method proposed it was intended to have the flood observation station on the Lesser Zab at a point well upstream of Altun Kupre. That point would be about 2 hours more remote from Baghdad than Bekhme. Carefully planned operation was essential.

With regard to Mr. Sevian's criticisms, Sir William Willcocks had shown that there was inadequate water in Iraq to irrigate the whole country ; but it was felt that the projects proposed by the Author would enable a considerable additional area to be brought under cultivation. Irrigation would, however, have to take a subordinate place to the all-important question of flood control ; and if that were born in mind the Author did not anticipate the difficulties suggested by Mr. Sevian.