Paper No. 6287

Engineering problems in recent river valley projects in India †

by

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Discussion

Mr A. M. R. Montagu said that careful examination of the Paper revealed a wealth of information, some of which he felt was not quite as accurate as it should be. A little more required further explanation. After all, one could not expect absolute accuracy when one was covering not only wear in turbine blades but accidents that happened 50 years and more ago, together with details of the design of one of the biggest dams in the world, all in one Paper.

73. In § 7 the Author remarked: "There is now a definite trend towards the construction of barrages rather than simple weirs. Requirements of limited afflux and high pond levels for effecting larger diversions of discharges into canals are the main reasons for this." Mr Montagu suggested that the prime reason was economy. It was more economical to build a relatively narrow and deep barrage than an immense weir extending across the full width of the river. As to limited afflux, he did not know how that was attached to barrages. The limited afflux was one of the advantages of a relatively low but long weir across the river.

73a. In § 8 (iv) the Author went on: "Steeper up-stream and down-stream slopes of the glacis to improve discharge coefficient". He did not think it did improve the discharge coefficient. What it did was to fix the standing wave, and that, of course, was of vital importance.

74. Mr Montagu had been personally connected in one capacity or another with some of the weirs illustrated in Figs 3a, 3b, and 3c. In the diagram of Marala Weir, which showed bays Nos 1–6 before reconditioning (Fig. 3a), the dimension from the downstream face of the upstream row of wells to the upstream face of the crest wall was 33 ft. In the diagram of Marala Weir after reconditioning (Fig. 3a) it was shown as 28 ft. Also, the distance between the upstream face of the crest wall to the face of the baffle stone which held the falling shutters was marked in the upper diagram as 14 ft and in the lower diagram as 8 ft and 3 ft, a total of 11 ft.

75. One of the diagrams was marked "Marala Weir before reconditioning" and the other "After reconditioning", but the third diagram in Fig. 3b was marked merely "Marala Weir". There the dimension from the downstream face of the upstream wells to the upstream face of the downstream wells was shown as 70 ft. Taking the totals on the two other diagrams, he found that they came to 85½ ft and 77½ ft respectively. He was not aware that any of the wells had been moved when reconstructing the weir.

76. In § 12 the Author listed the causes of failures of weirs. The direct cause of the failure of most of the weirs of which Mr Montagu had knowledge was faulty regulation. Weirs might be damaged and endangered, but intelligent regulation and intelligent direction of flow even in floods could do a very great deal to minimize damage to permit of repair at a later date.

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† Proc. Instn civ. Engrs, vol. 11, p. 1 (Sept. 1958).

77. In § 12 (i) the Author referred to the Islam Weir. The Islam Weir was one of the most remarkable accidents which had occurred in the history certainly of Punjab irrigation and possibly irrigation in India. The Punjab Government had constructed four barrages, three on the Sutlej River and one just below the junction with the Indus. The construction of those barrages had resulted in heavy silting upstream of each and practically clear water emerging below. That in turn had led to very heavy silt pick-up. That was a phenomenon with which up to that date those concerned had not been acquainted. It was certainly the prime cause of the Islam failure. Nevertheless, it had reaffirmed the conviction of those who were in any way connected with the administration of the department at the time that a little intelligent regulation would have saved three bays of that weir and three 60-ft gates. The Author mentioned faulty regulation in § 12 (iv). It was a great relief to know that all those causes of failure were fully guarded against in the design of modern barrages, presumably including faulty regulation.

78. In § 64 the Author stated that canals generally were designed according to either Lacey or Kutter. Although Kennedy undoubtedly used the Kutter equation, he supposed that Kennedy, *per se*, had had more influence on the design of channels in India than any other single individual until Mr Lacey arrived on the scene.

79. Table 4 (a) gave data for canals without stating any dates. For example the data for the Western Jumna Canal was recorded—discharge, 9,000 cusecs; bed width, 200 ft; full supply depth, 7·25 ft; slope 1/1,000. These dimensions only applied to the conditions subsequent to 1945. Prior to remodelling, the Main Line Upper had been nothing but the bed of an old torrent. At Dadupur the discharge had been diverted from this torrent into the canalized channel known as the Main Line Lower. In this old torrent bed, 20% of the discharge admitted at the Tajewala head works had been lost in the 7 miles between Tajewala and Dadupur. By 1939 the value of water had been such that drastic remodelling of the Main Line Upper had been justified solely to economize on the heavy losses.

80. In 1939, he, Mr Montagu, had been charged with the duty of remodelling the Canal, to permit of water being supplied to an area known as the "Arid Area Extensions". Much of this additional water had been derived from the saving in seepage losses mentioned, by realigning and canalizing the Main Line Upper. Since the torrent had a heavy shingle bed, the new channel had had to be constructed in the same material. It was not a "Lacey" channel in any sense. The excessive slope of the torrent was only reduced to 1/1,000 by construction of four very large falls of the semi-gravity parabola type, and this heavy slope was only justified by the material in which the channel had been constructed. To quote these unusual dimensions without any explanation, therefore, was in his opinion, very misleading.

81. It would have been far more informative if the Author had quoted the dimensions of the Main Line Lower.

Sir Claude Inglis (formerly Director of the Indian Waterways Experiment Station at Poona and later Director of the Hydraulics Research Station, D.S.I.R.) said that the Author had been very generous in his complimentary remarks about the pioneers of irrigation in India of 100 years ago, but had said practically nothing about the wonderful work done in the first half of the 20th century, particularly between 1919 and 1945, when the concept of regime—on which modern loose-boundary hydraulics was based—had been evolved, and the use of large-scale loose-boundary models initiated and developed.[1]

83. He raised the point because nearly all the work done recently had been based on work carried out many years ago. For instance, the Author when referring to improvements in the design of barrages, in § 12, said that these included increasing the depths of water on the downstream pavement in order to dissipate energy; increasing the weight of the downstream pavement to withstand uplift pressure; deep cut-offs to prevent piping, and adequate stone and block protection were all standard features of the new designs. None of these was new; they were the practice when the Sukkur

Barrage was built, based on model experiments carried out at Poona 30 years ago.[2]

84. However, the point with which he was in greatest disagreement concerned the effects of the works already built or now in progress. The impression was given by the Paper that all these works were going to be beneficial to the country. In his opinion that was not so; because many difficulties would arise hereafter as a direct result of works now under construction. The Author referred to flood control by detention reservoirs, embankments, diversion of flow into other basins and reduction of soil erosion. Unfortunately only the last of these was of permanent value. In the case of a river like the Kosi the amount of silt coming down was so enormous that after a relatively short period of years the detention reservoirs, the lands inside the embankments and the adjoining basins would silt up, and when that occurred the position would not be improved but would be much worse. It must also be remembered that although flood spill is always referred to as though it were an unmixed evil, causing heavy losses, spill in many areas greatly increases the fertility of the soil due to deposition of silt. Thus, as a result of the breach in the right bank of the Indus in 1942 when 2,600 square miles were inundated, yields were increased by some 50% and the benefits far exceeded the losses.

85. However, by far the worst damage resulted from the extension of perennial irrigation rendered possible by the construction of barrages, upstream of which water levels were being maintained about 5 to 20 ft higher than previously in the winter season. As a result silting was taking place upstream, causing a gradual progressive rise of water levels farther and farther upstream, and where the barrages were not far distant from each other—20–30 miles—there was actually a pond the whole way. This, combined with the application of irrigation water and percolation from the channels, had caused a rapid rise of the subsoil water table and consequent salt efflorescence; but even where the subsoil water table had not risen close to the surface the application of irrigation water would—where the rainfall was small—lead to salinization after a period of 100 to 200 years, although the irrigation water contains only a small quantity of salts in solution.

86. The seriousness of this menace was exemplified by the area of land going out of cultivation owing to salinity in the Southern Punjab, which was estimated to be about 50,000 acres per year. Prevention of salinization by the provision of adequate drainage and soil treatment had not been faced up to, on the ground that the cost would be prohibitive; but it was not a question of cost, but of the life blood of the country.

87. Finally he wished to deal with the question of erosion at Dibrugarh on the south bank of the Brahmaputra, between 1950 and 1956, discussed by the Author in § 49. As a result of the great earthquake of 1950 in that area, a large number of avalanches had occurred along the range of mountains which run parallel to, and not far distant from, the right bank of the Brahmaputra. Much of the debris had been subsequently washed into the river, and as a result the right bank channel, though still persisting, had deteriorated, but the chief cause of the erosion along the south bank, which had destroyed a large part of the town of Dibrugarh, had been the tremendous quantity of sand washed into the river, to be then washed downstream as a very heavy bed charge, which had caused the bed of the river to rise by no less than 10 ft in 5 years. Experiments[3] carried out at Poona between 1944 and 1946 had shown that the heavier the charge of sand the wider a channel became, and it had been this very heavy charge that led to a marked increase in the width of the river which had been the direct cause of the south bank erosion.

88. In 1953 an attempt had been made to protect the bank by constructing spurs; but these had been washed away. In the following year short, strong spurs of stone and porous wooden groynes had been constructed, and further erosion had been checked. Without in any way wishing to detract from the excellence of the design and construction of the spurs built in 1954–55, he held that had those spurs been constructed a year earlier when the river was still widening and eroding, they too would have failed; but built when they were they undoubtedly had been useful in stabilizing conditions.

Mr Gerald Lacey (Consultant, Sir M. MacDonald and Partners) said that he was glad to note the Author's tribute to the work of two pioneers of irrigation works in India, Sir Proby Cautley and Sir Arthur Cotton. Both had been officers in the employ of the Honourable East India Company, the former in the Bengal Artillery and the latter in the Madras Engineers. These two great engineers had first seen service in India in 1819, and since those early days there had been many worthy successors. From his own experience in the United Provinces he could quote the names of Sir Bernard Darley who had been responsible for the Sarda Canal, and Sir William Stampe who had pioneered the hydro-electric development of the falls on the Ganges Canal and applied the power to pumping from tube-wells for irrigation.

90. The Author had referred to the "Lacey formula" for the minimum width of stable waterway of an alluvial river with a sandy bed $W_s = 2{\cdot}67\ Q^{\frac{1}{2}}$ and had commented that the present-day width of weirs as designed from this equation were somewhat tight. The value of q the discharge in unit width had been raised from a figure of 100–200 to 300–400. But, without reference to tightening it was evident that $q = 0{\cdot}375\ Q^{\frac{1}{2}}$ and that the discharge intensity was a function of the discharge.

91. The width equation applied to an unrestricted river which was free to scour and had a well-defined thalweg. When it was applied to the design of an irrigation diversion work constructed across a river, much depended on whether the work was a weir, in which case there was a horizontal bar across the channel, or the work was a well designed barrage. In the latter case it was assumed that with all the gates fully opened the river would flow unimpeded through the barrage and would not differ greatly from a bridge.

92. When the work was a weir there was always the difficulty that the river was "combed out", the thalweg was destroyed, conditions upstream were indeterminate and shoaling once established by a small bed obstruction would persist. In such circumstances a long weir was possibly the safest, and, if the weir was built in the river and not in the dry in a diversion, was easier to construct. A barrage which imposed minimum restrictions on the river during high floods had manifest advantages. A barrage could be made shorter but there was obviously a limit to which it could be permitted to throttle a river.

93. In Table 3 the Author had tabulated values of the looseness factor for a number of works. Of these the Nangal barrage, said to be a high weir built on conglomerates at a site where the river was still in the boulder stage, formed a striking exception to the general rule. This appeared to be a case of genuine throttling—doubtless for good and sufficient reasons. For the rest it would appear that normally a looseness factor of 1·25 could be applied, and when the river transported a very heavy charge, 1·50.

94. The Author in his synopsis had referred to the lessons to be learnt from a study of failures but when referring to the failure of the Sarda Barrage undersluices had omitted comment on the extent to which faulty regulation might have contributed to that catastrophe. He (Mr Lacey) was glad that he had not been Chief Engineer when the damage occurred. Fig. 3c showed that the barrage was designed to pass a high flood, when all the gates would be open, with a loss of head of 2 ft. Fig. 5 suggested that some time during the flood of 1956 an entirely disproportionate discharge had been forced through the sluices in a disinterested attempt to observe the result. The observed water-surface profile on 9 September was sufficient to indicate the risks which were being taken. In order to obtain the true picture it was necessary to know whether all the gates of the barrage proper had been open or if some had been closed. It was also necessary to know the normal "pond level" upstream of the barrage consistent with operating the canal with full discharge and also to know whether on this occasion levels upstream had been raised *above* "pond level" in order to force increased supplies down the Sarda Canal at a time of keen demand. (There might have been heavy "silting" in the head reach of the canal.)

95. The modern tendency was to increased mechanization and improved devices but the responsibilities of those in charge of large headworks were very heavy. There was too much talk of taming rivers—rivers were at all times very much alive.

96. There was much to be said when falling gates were installed on a weir to make them as simple as possible. The gates on the Okhla weir of the Agra Canal were an example. In many cases such simplicity was not feasible owing to the height of the gates. The tragic loss of five engineers' lives in an attempt to repair the damage due to the failure of automatic interlocking gates, and the suddenness of the flood which had been at the root of the disaster emphasized the unceasing nature of the battle which the engineer waged against a river.

97. The figure for the slope of the Sarda Canal given in Table 4a of 1/500 should have been nearer 1/5,000 and the bed width was surely more than 220 ft. The correct discharge and other dimensions had been given by Darley.[4] The bed-widths of unlined channels quoted in Table 4b were fairly concordant with the minimum width relationship. The scales given in Table 5 for large models were in agreement with the scales he (Mr Lacey) recommended but with small models some modification would be required as shown in his recent Paper.[5]

98. When the Author stated that canals were generally designed either according to Lacey or Kutter it would be more correct to say "Kennedy-Kutter".

Mr A. E. Griffin (Consultant) said that nature had been not unkind to the subcontinent of India when compared with the area served by the Nile. If the annual run-off of 1,356 million acre-ft mentioned by the Author was divided by the total area of India, it gave at least 18 in. of water over the whole country. If a similar calculation were made in respect of the Nile, using the combined areas of Egypt and the Sudan to give about the same area as India, the result was a depth of rather under 1 in. of water. If it were assumed that Egypt got all the flow, the result was rather under 3 in. Therefore, the irrigation potential or general water potential in India was obviously very big compared with certain other regions. Compared with West Pakistan the contrast was nothing like as wide, but even assuming very good conditions there, the Indian coverage would be at least 50 per cent in excess of that of West Pakistan.

100. With regard to barrages, he had had the good fortune, being a foreigner to the Indian irrigation service, to see most of the barrages referred to in the Indus basin, and he was exceptionally interested in the Trimmu barrage because it was the subject of a paper by Haig which was read to the Institution in 1941.[6] Many of those who had been concerned with the design of barrages had found that Paper extremely useful because it presented a rational, scientifically supported build-up for the design of practically every component of the work.

101. The figures in the Paper of the various barrages were interesting, but he would have liked to see the maximum permissible head indicated more clearly. In the case of old weirs, that was probably difficult but with some of the others it could have been given since it was a crucial figure in the design.

102. It would be seen from Table 3 that what was called the "looseness factor" suddenly dropped in the case of the Harike and Nangal Dams. Why had that sudden drop occurred?

103. The Author stated that there were already 10 million acre-ft of storage in India and there were going to be a further 85 million acre-ft, making a total of 95 over the two 5-year plans. That was nearly $1\frac{1}{2}$ times the total annual flow of the Nile. What had been the Indian experience with silt precipitation in reservoirs? The Indians had several reservoirs which had been in action a long time, and they must have some figures of the rate of silting having regard to the silt charge in the rivers involved. In Egypt the policy to date had always been to avoid storing heavily silt-laden water and this called for a dam with a large sluice capacity near the bed of the river, and special methods of regulation. Had India dams of this sort and were they being operated on the same lines? It was questionable whether the present Nile policy could be carried on indefinitely in view of the increasing value of the water becoming a very vital economic factor as the years went on. Probably, the future policy must be that when one dam silted up one simply built another. However, that was limited by the number of sites available. Although advanced construction technique might make the choice of dam

sites a much wider one, it still seemed to him that there were limitations in that respect, as, for instance, in the Indus system of rivers where the silt charge was far heavier than that in the Nile. It would be interesting to hear what the estimated life of the Bhakra Dam was.

104. Tables 4a, 4b, and 4c gave some very interesting particulars of canals, but it would have given the volumes of earthwork more meaning if the milages had been quoted.

105. A striking feature of the Paper was that, in spite of all the great canal systems which had been mentioned, there had been no mention whatever of drainage systems. Surely, with those huge canal systems, there must be some great drainage systems like those in the Delta of Egypt. He wished to support the remarks that had been made by Sir Claude Inglis about the lack of drainage. In the Punjab and in Sind, he had noticed that drains were not in great evidence. There certainly were drains but they did not appear to be given the importance that they were in Egypt. He had mentioned that on occasions to the engineers concerned and the general reaction was that there were difficulties—one being insufficient slope. Speaking generally, he felt that the engineers there were not as drainage minded as the Nile engineers. In the Punjab, there were much better slopes than in the Delta of Egypt or the Gezira of the Sudan. In Sind, the problem was somewhat similar to the Delta problem. The Nile engineers had paid more attention to drainage and he thought that they had reaped the benefit of doing so.

Mr F. Newhouse (Sir M. McDonald & Partners, Consulting Engineers) applauded the Author's recognition of India's present indebtedness for the work done in the past by British engineers.

107. His own view about irrigation works was that they should be built to last for ever, and that was fortified by the slide which the Author had shown, in his introduction, of the barrage which was 1,000 years old. Could it be imagined that any work which had a lot of steel in it as an essential part of its structure would last 100 years, to say nothing of 1,000 years? Reinforced concrete had been used instead of mass concrete in an effort to reduce the cost of unwatering. There were serious doubts about the life of reinforcement in concrete. Attempts were made to make concrete impermeable but he did not know of any concrete which was actually impermeable. Therefore, the steel in the concrete would be attacked, and it would be attacked over decades and perhaps centuries. Consequently, such irrigation works were not for ever; they were for a short time only.

108. He hoped that that argument (that it was not necessary to construct a passage to last for a long time because it would be made useless by silt) would not be brought forward. Instead, the feeling should be that if the dam could be made to last for 50 years instead of 25 years it was worth while. Indeed, he thought it should stand for 1,000 years, and could be designed accordingly from the silting point of view.

109. The same remark applied to the use of sheet-piles instead of wells in the foundations. Sheet-piling was supposed to be watertight, but was it? If one wanted to prevent the flow of water through the cut-off, the only use one should make of sheet-piles was to have two rows of them and fill in between with concrete, because with one row one had no security whatever that there was not piping going on right from the moment that one had driven them.

110. Mr Newhouse made a plea for more attention to the wider question of the value of works which added to the facilities for cultivation without regard to the population problem and ancillary difficulties. Engineers were frequently accused by administrators of not giving (or being unable to give) due consideration to the wider problems of humanity and of being narrow-minded technicians rather than members of a widely educated and broad-minded profession. Such accusations were manifestly ill-informed and should be refuted by example.

Mr P. S. A. Berridge (Assistant Engineer (Bridges), Western Region, British Railways;

formerly Deputy Chief Engineer/Bridges, North Western Railway, India) observed that rivers free to meander in the Plains, like the Kosi which had moved 75 miles westward in 60 years, choked their beds and altered their courses. In the Punjab, however, where the railway ran parallel with the mountains, the rivers were controlled and made to keep to their courses wherever they were bridged. There was, he said, evidence of the silting up of these river-beds at the rate of 5 ft in 100 years. This was leading to periodical flooding of steadily worsening magnitude. The resultant loss of life and damage to property underlined the urgent need for action to prevent these catastrophes in the future.

112. The Author had mentioned in § 47 four ways of controlling the rivers issuing from the Himalayas on to the Plains—namely by the construction of detention reservoirs; by raising artificial river banks; by diverting one river to another river by canal; and by delaying the run-off by increasing the growth of vegetation and minimizing soil erosion in the foothills. Mr Berridge thought that only the first of these remedies seemed likely to offer a real solution to the problem. He asked if the Bhakra Dam could contain the whole monsoon precipitation in the watershed of the Sutlej and so provide control by which the level of the river in the Plains could be prevented from rising to danger level. If that could be done on the Sutlej, similar detention reservoirs ought to be constructed on the Jhelum, Chenab, Ravi, and Beas rivers; and even though the problem was international and aggravated by the fact that the dams across these rivers would have to be located in Indian territory to prevent flooding in Pakistan, the problem was most acute and should not be shelved.

113. Mr Berridge also asked the Author if he could give any indication of whether or not the average precipitation in the Himalayas was on the increase.

Mr W. R. Rangeley (A Senior Engineer of Sir Alexander Gibb & Partners) said that there was an indication in the Paper that there was enormous scope for future development of irrigation in India. For example, despite the extensive programme described in the Paper, of the total mean annual discharge of all river systems—that, he assumed, meant the main river systems—which amounted to some 1,400 million acre-ft, the total reservoir storage capacity at the end of the second 5-year plan (which ended in 1961) would be no more than about 7 per cent. That was 95 million acre-ft total storage capacity against 1,400 million acre-ft.

115. It should also be recalled that the expansion in the irrigated areas during the first 5-year plan was from 51 million acres to about 67 million acres in 1956, and during the same period the production of food grains improved from 54 million to 65 million tons/year. About two-thirds of the food grains produced in India were in the form of paddy rice, and since most rice was produced under irrigation the increase in the grain production was largely attributable to the projects described in the Paper.

116. Had there been a comprehensive survey of the irrigable areas of India? He would welcome some figures. What were the economic factors which were used to decide which of the many feasible irrigation projects should be included in the first two 5-year plans?

117. He differed cordially from the Author on the matter of betterment of agriculture as against extension of irrigable areas. As time went by, the development of further irrigated areas would become more expensive, and therefore it seemed to him most important that improvements in agriculture should keep pace with developments in irrigation engineering.

118. Referring to the brief particulars of the various projects which were given in Table 1, he asked if the costs were comprehensive and included the total capital cost of canalization, drainage, and agricultural development as well as the major civil engineering works. If they represented total costs of the projects, the unit cost per acre appeared to be relatively low by world standards and in many cases was of the order of £20 per acre. Could the Author give further information on the unit cost per acre, and state whether the areas given in the Table referred to the net cultivable land or the total area

devoted to the scheme? Could some indication be given of the ratio between the annual charges on those projects and the benefits to be derived from production?

119. Concerning the earth dams described in §§ 35–43, could the Author give some information about the permeability of the impervious material used, for example, in the Panchet Hill dam and the Maithon dam? The solid discharge of the Himalayan rivers was large. What allowance had been made for siltation in the new projects described in the first part of Table 1, and had any special measures been introduced to minimize the rate of siltation in the smaller reservoirs? For example, had any work been done on density-current phenomena? Was the water carried by the proposed long prestressed siphon referred to in § 68 silt laden, and, if so, did that present any special problems? Was salt accumulation a serious problem with rice as well as with dry-foot crops?

120. He would welcome more information on the methods of control used in the distribution system. If the costs given in Table 1 were comprehensive ones, it seemed that the system of canal regulation must of necessity be simple. Had automatic control been tried in India, especially for paddy irrigation?

121. Could any figures be given for the seepage losses through tiled lining such as the example shown of the Haveli Main Canal? Comparative figures for irrigation conveyance efficiency before and after canal lining would be particularly interesting.

Mr J. K. Hunter (Consultant, Sir Alexander Gibb & Partners, Consulting Engineers) said that the Ganga and Sarda canals were supplied by uncontrolled Himalayan rivers and took off at points where the natural fall of the country was much steeper than the gradient which could be tolerated in the canals themselves. Because of that the original design of the main canals embodied a series of falls in which the potential energy of the water was dissipated in stilling pools. The power represented by those falls had remained unused until about 1925 when a small station had been built at Bahadrabad on the Ganga Canal to give local supplies of electricity. Later, Sir William Stamp, when he became chief engineer of what had then been called the United Provinces Irrigation Department, had taken up the idea with enthusiasm. During the 1930s a series of small power stations had been constructed on the Ganga Canal, and it had soon become apparent that there were advantages to be obtained from building a bypass canal when the old falls were not too far apart and concentrating in one spot the head available at two or more adjacent falls. The last of those power stations of which he had personal knowledge was that at Mohamadpur where a head of 20 ft had been developed by combining two falls. Since that time the Pathri power station had been constructed with a head of 31 ft.

123. The Sarda Canal had been constructed about 70 years later than the Ganga Canal, and its falls were very much lower. Because of that, it had in the 1930s been judged to be uneconomic to attempt to develop the Sarda Canal for power, however, the success attending the later developments on the Ganga Canal had led to a review of the possibility of developing power from the Sarda Canal, and Mr Watal, who succeeded Sir William Stamp, had proposed that a series of falls near the head of the Sarda Canal should be combined to produce a head of 60 ft. That was the Khatima power station, which was referred to in the Paper under the head of the Sarda Canal. From the point of view of the power-plant cost and the concentration of control in one spot, the idea was an excellent one, but it had involved laying the foundations of the power house on alluvial gravels at a depth of 65 ft below the ground-water table. The resulting difficulties and delays had been very serious, and they had greatly increased the cost of the scheme. In that respect the earlier works on the Ganga Canal had been much more fortunate. Even Mohammedabar, which developed a head of about 20 ft, had been constructed without difficulty in the dry and with very little pumping, and this in spite of the fact that the deepest portions of the foundations had been 17 ft below the water table. The later station, Pathri, with a head of 31 ft, had been a more ambitious project combining a larger number of falls. Because of that it had run into trouble, for it required the foundations to be laid 35 ft below the water-table.

124. The difficulties which might arise from the existence of a high water-table had a bearing on the extent to which it was justifiable to concentrate power development under the conditions encountered in the sub-montane tract of the Himalayas. In the case of the Khatima power station it certainly posed the question whether it would in the event have been more economical to have adopted a two-stage or possibly even a three-stage development instead of the single-stage development which had been carried out.

125. Another problem which might arise with power stations constructed on irrigation canals was the amount of suspended and rolling bed material which might be carried in from the main river. In the case of the Ganga power stations this had not been a serious matter, but it had proved very troublesome at Khatima on the Sarda Canal.

The following contributions were received in writing.

Mr Karunamay Ray (Consulting Engineer, Calcutta) asked what proportion of the 315 million acres under cultivation (§ 3) could be considered as irrigated by river valley projects; how much by Government channels; and how much by other channels. According to "India 1958" it appeared that in the period 1946–7 to 1955–6 the total land irrigated by all channels increased by 7·85 million acres (from 48·45 to 56·30 million acres). The increase in area of land irrigated by Government channels could be estimated at 3·68 million acres. How did the costs incurred by that 3·68 million acres increase compare with the costs incurred by other channels for the remaining increase of 4·17 million acres?

127. How was the total expenditure of £1,280 million (§ 6) to be apportioned between irrigation, power, and flood control?

128. "India 1958" put the production figure of cereals and pulses at 68·69 million tons, while the Author gave a figure of 65 million tons (§ 3). Could the Author explain the difference?

129. In § 4 the Author had suggested that irrigation projects led immediately to increase of yield per acre. That was true only when the water was released to the fields by means of the canals; and for that the works of the Canals Division should be fully synchronized. Was that so? Were the canals completed at the same time as the reservoirs?

130. The Author stated that the River Kosi had shifted 75 miles during 60 years and also mentioned that barrages and embankments now constructed would control the rivers. It would, therefore, be assumed that the rivers under the controlled conditions would not shift and the economic life of these projects could be expected to be reasonably high. This should go a long way to provide relief to water tax. Could the Author provide some observed data with regard to the silt-load of the Kosi upstream and downstream of Hanumannagar Barrage.

131. Information with regard to the data adopted for the ratio of the dead storage and the live storage in the various dams, constructed and under construction in India, would be helpful.

132. While describing the failure of certain barrages, the Author had not dealt with retrogression. In the case of the Durgapur Barrage, retrogression of 7 ft was said to have been adopted as against the usual retrogression of 4 to 5 ft of downstream level. Could the Author provide information as to how the observed figures compared with the adopted figures for the design of the weirs (both existing and newly constructed); and, also, if there had been any recovery of the downstream levels.

133. On reference to Table 3, it would be seen that the design flood discharge for the Durgapur Barrage had been taken as $4{\cdot}6 \times 10^5$ cusecs. Presumably this figure related to what was proposed for adoption; the actual adopted discharge was said to be $5{\cdot}5 \times 10^5$ cusecs, the actual flood observed being $6{\cdot}5 \times 10^5$ cusecs. The looseness factor should be about 1·15 instead of 1·25.

134. The Author stated that in India, the Lacey and Kutter formulae were generally

adopted for the design of the canals; but, for alluvial soils, some experts had examined the Lacey, Kutter, and Kennedy formulae and had recommended the adoption of a modified formula. Mr Ray could not see why the Lacey formula was considered unsatisfactory. Could the Author provide some observed data to settle this point?

The Author, in reply, said that economy was not the prime reason for preferring barrages to weirs. Where, in India, pond levels were not too high, weirs were found to be cheaper. In a barrage it was possible to keep the crest at a low level, maintaining the required pond level by means of gates of suitable height. In a weir, since the heights of the falling shutters was generally limited to about 6 ft, the crest of the weir had to be correspondingly higher to get any desired pond level; a lower crest would result in less afflux with the same looseness factor. The barrage, therefore, affords more flexibility of operation and better control of a river.

136. The results of experiments on a hydraulic model of Hanumannagar Barrage across the Kosi River were summarized in Fig. 25 and it could be seen that the discharge coefficient could be improved by suitable upstream and downstream glacis slopes.

137. The Author did not think that Mr Montagu's criticism of the accuracy of the drawings was relevant to the discussion. He had, however, checked them carefully and had found a few errors. Fig. 26 gave the corrected forms of the cross-sections of Marala weir (see Figs 3a and 3b).

138. Table 4a (p. 38) had been included in the Paper to give a general picture of some of the longer old canal systems, without any attempt to justify the relative hydraulic dimensions adopted. In the case of the Western Jumna Canal, the bed was in the boulder region and steeper slopes were possible. The corresponding figures for the Main Line Lower (unlined) were: discharge, 8,000 cusecs; bed width, 215 ft; full supply depth, 10ft; water-surface slope, 1/8,000.

139. Sir Claude Inglis had referred to the Kosi project and doubted its efficacy in the long run. Kosi River caused the worst damage in India, owing to lateral shift, and investigations had been in progress for a long time. The present scheme had been drawn up as the first-stage works to control the river; further works were to be undertaken in future. Investigations for evolving soil conservation measures had been started with a research centre at Chatra at the foot of Himalayas.

140. Waterlogging was a severe problem in the Punjab, for a number of reasons: there were few natural streams owing to low rainfall; the construction of roads, canals, etc. caused further obstruction to drainage; the country was flat; there was intensive perennial irrigation (of the total cultivated land, two-thirds was irrigated). Some counter measures, such as tubewells and drains were being undertaken and others were being investigated. In the rest of India, waterlogging was of little moment, although irrigation has been practiced for centuries.

141. It was not correct that spurs constructed in 1953 at Dibrugarh, in an effort to protect the right bank of the Brahmaputra, had been washed away. In fact, in 1953, a length of stone revetment had been tried. The Author had believed that this would not be satisfactory and had designed instead a system of short spurs which had been completely successful.

142. The flood discharge through the Sarda Barrage (see § 94) at the time of failure in October 1956 had been 370,000 cusecs, of which 85,000 cusecs were passing through four 50-ft-wide bays of undersluices. (At that time of year there was not a heavy demand for water from the Sarda Canal.) The Author believes that the failure was probably a result of accumulated damage over a number of years caused by a standing wave forming beyond the floor so lowering the downstream water levels—by retrogression—below designed levels.

143. The figures given in Table 4a (p. 38) for the Sarda Canal referred to the original design, but the slope, given as 1/500 in the MS. of the Paper was in fact 1/6,500 [*sic*]. For the canal as completed in 1931, the figures were: discharge, 9,500 cusecs; bed width, 350 ft; full supply depth, 8·1 ft; water-surface slope 1/5,500 [*sic*]. The canal was now being remodelled to carry a greater discharge.

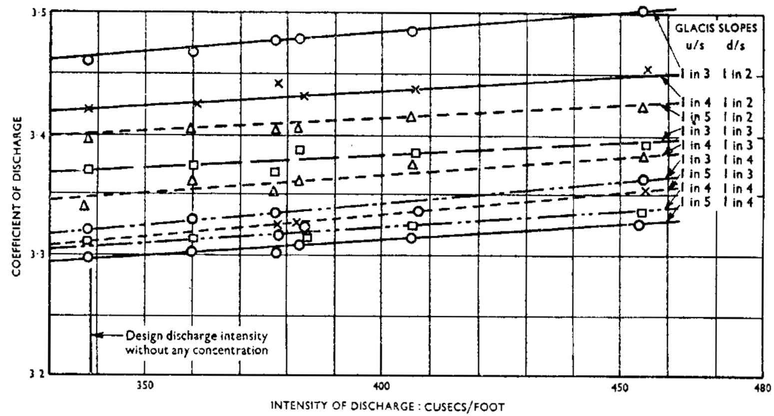
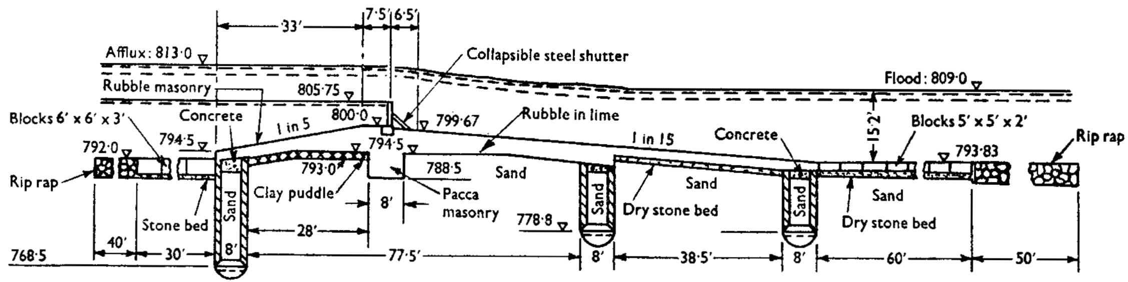


FIG. 25.—COEFFICIENT OF DISCHARGE FROM $q = cd^{1\cdot5}$) PLOTTED AGAINST INTENSITY OF DISCHARGE FOR DIFFERENT WEIR PROFILES AS OBTAINED UNDER FREE-FLOW CONDITIONS IN 1/40-SCALE MODEL OF HANUMANNAGAR BARRAGE GLACIS SLOPES

(a)



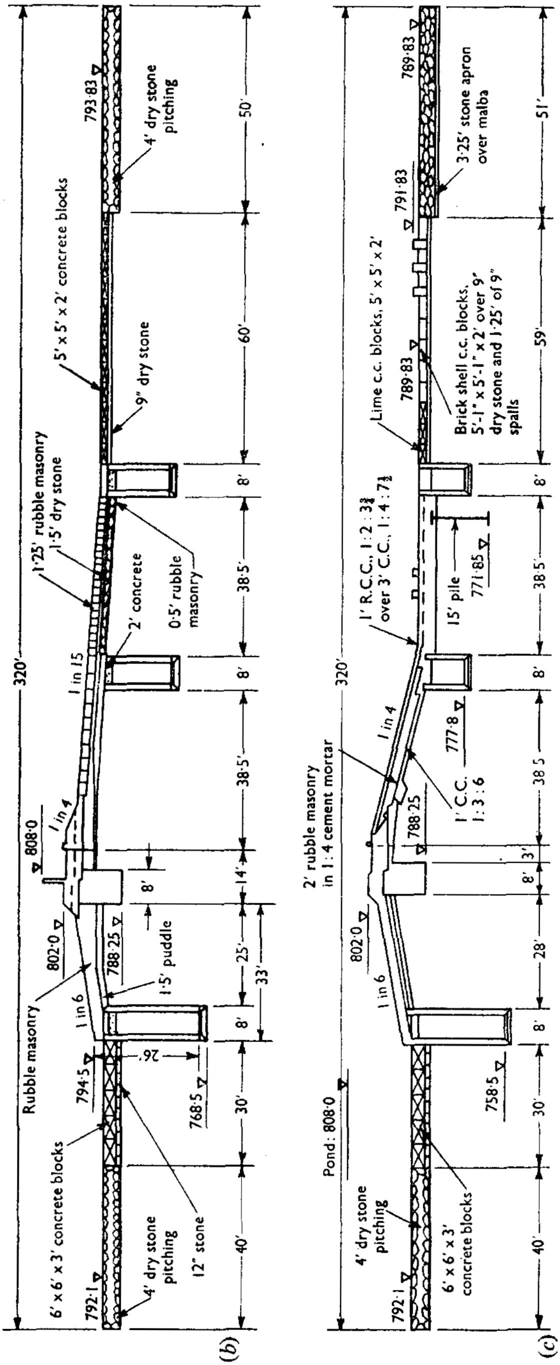


FIG. 26.—CORRECTED PROFILES OF MARALA WEIR (SEE FIG. 3) (*a*) ORIGINAL (1880); (*b*) BEFORE RECONDITIONING (BAYS NOS 1 TO 6); (*c*) AFTER RECONDITIONING

144. Table 6 showed the maximum heads (§ 101) for which the weirs mentioned in the Paper had been designed.

145. At Nangal, the river was in a boulder region so cutting into high banks to provide a water waterway had been unnecessary. For Harike Barrage the looseness factor had been reduced to 0·97; a higher factor would tend to create shoaling and other difficulties in the proper control of the river.

TABLE 6.—MAXIMUM HEADS ACROSS WEIRS AND BARRAGES, EXPRESSED AS DIFFERENCE BETWEEN POND LEVEL AND D/S FLOOR LEVEL OR LOW-WATER LEVEL, WHICHEVER IS THE GREATER

	Feet
Khanki headquarters, before reconditioning	13·0
,, ,, after ,,	18·0
Islam Weir, before reconditioning . . .	18·3
,, ,, after ,, ...	23·5
Marala Weir, before ,, ...	14·2
,, ,, after ,, ...	18·2
Mahanadi Weir	8·0
Godavari Weir	16·3
Sukkur Barrage	24·5
Trimmu Barrage	24·0
Hanumannagar Barrage	34·0
Sarda Barrage	13·8
Kala Bagh Weir	22·0
Nangal Dam	53·0

146. Table 7 gave the rate of siltation for several existing Indian reservoirs. Correlation of the rate of silting in a reservoir with the area of its catchment, its most important contributing factor, was fairly straight-forward if the type of catchment is uniform. Dr A. N. Khosla had worked out the rate of annual sedimentation of north and central Indian rivers as 75 acre-ft for a drainage area of 100 sq. miles. This gradually increased to about 272 acre-ft as the area reduced to 10 sq. miles.

147. In certain Indian reservoirs, like the Hirakud, a large percentage of the flood waters of the months of June to September were passed through the sluices at bed level, as in the case of Aswan Dam, Egypt. Hirakud Dam had sixty-four sluices, which passed about 70% of the maximum flood.

148. The sedimentation theory could be used for calculating the life of a reservoir. The siltation was assumed to take place in three stages. In the first stage, silt was formed completely to the sill level of overflow sluices or spillway. In the intermediate stage, the river overflow formed a regular channel in the same way as a river finds its way through a delta. The width and depth were so formed that for annual maximum discharges, there would be neither scour nor silting-up of the watercourse. In the third stage, the rate of deposition of silt was very slow and so the reservoir would function for a longer time than would be predicted by a straight-line computation. The loss of reservoir capacity for the Bhakra dam had been computed by working out the advance of the upper and lower delta deposits of silt in the reservoir; an abstract of the results was given in the Appendix on p. 477.

149. Milages and quantities of earthwork involved in the works detailed in Tables 4b and 4c were given in Table 8.

150. The Author agreed with Mr Griffin that some mention of the drainage system should have been made in the Paper. In peninsular India and many other States in the north, the costs of the drainage systems were included in the costs of the canal systems. Thus ample provision was made for the drainage system in the Kosi Canal estimates.

But in a few States like Punjab, similar attention had not been paid to drainage. This had resulted in the waterlogging mentioned in § 140.

151. It was a sound suggestion (§ 109) to use two rows of sheet-piles with concrete between them to serve as a cut-off in a weir. But when no wells were employed, and sheet-piles were used as cut-offs, a single row of piles had been found sufficient for all the weir and barrage works in India.

152. The Bhakra Reservoir had an effective capacity (§ 112) of 5,600,000 acre-ft. The average monsoon flow in Sutlej was about 10,000,000 acre-ft and during the monsoon period there was a continuous flow through the sluices for perennial irrigation lower down. Thus the Bhakra Reservoir would be able to achieve a substantial degree of flood control. A similar solution was possible for the other rivers mentioned in

TABLE 7.—OBSERVED RATE OF SILTATION FOR SEVERAL INDIAN RESERVOIRS

Location	State	Total silt deposited		Rate of siltation		
		Millions of cu. ft	Acre-ft	Millions of cu. ft/year	Acre-ft/year	Depth: ft/year
Mettar	Madras	676 (1941–48)		84·5		
Ekruk	Bombay	893		11·6		
Mayni	,,	107·4 (75 years)		1·43		
Pingli	,,	89 (69 years)		1·3		
Khadkvasla . . .	,,			12		
Nehr	,,	108·4 (62 years)		1·75		
Mhaswad . . .	,,	1,277		24·09		
Vanivilas Sagar . .	Mysore					0·25
Darna	Bombay				Negligible	
Chandpur . . .	Madhya Pradesh		1,172·6		53·26	
Sarathi	,,		1,561·3		70·96	
Beri	,,		311·4		22·3	
Tandula	,,		1,172·6		53·26	
Maramailli . . .	,,		519·5		25	
Ghagar . . . . (main dam)	U.P.	240 (1916–45)		8		
Mala	M.P.					1·5

§ 112, but there were two serious limitations to the construction of big reservoirs on Himalayan rivers. There were few suitable sites for high dams and the foundation rock was generally not very satisfactory, so the projects became very expensive, as at Bhakra. So far as was known to the Author, there were no definite indications of increased precipitation in Himalayas.

153. A comprehensive survey (§ 116) of the irrigable areas of India was in progress. It was anticipated that the irrigable area would be about 50% of the total sown area. The main considerations in selecting the irrigation and multi-purpose projects in the plans were: (*a*) well investigated projects on which preliminary work was done; (*b*) benefits by way of additional food production; (*c*) good percentage return; and (*d*) regional considerations.

154. The costs given in Table 1 were comprehensive and included the total cost of

TABLE 8.—MILAGES OF CANAL SYSTEMS DETAILED IN TABLES 4a AND 4b

Name	Length: miles
Bhakra Nanga project:	
Nangal Hydal Canal	40
Bhakra main line	108
branches	550
Gandak irrigation and power project (Bihar)	
Main western Canal	86·35
Rajasthan Canal project:	
Main canal	425
Branches	500
Ram Ganga River project:	
Feeder channel	46·3
Kosi project, East Canal:	
Main canal	29
Branches	220
Chambal Valley development:	
Right and left Rajasthan canals	81
Branches	99
Tungabhadra project (low-level canal):	
Main left and right canals	352
Hirakud Dam project:	
Bargarh main canal	55
branches	450
Kakrapar project (left-bank canal):	
Main left and right canals	80
Branches	660
Nagarjunasagar project:	
Main right-bank canal, 1st phase	135
final ,,	276
Main left-bank canal, 1st ,,	108
final ,,	140

canalization and drainage as well as the major civil engineering works. The unit costs per acre for some of the projects which are purely for irrigation were:

Kosi project	£23·6
Kangsabati	£25
Kakrapara	£15
Kadana	£20·8
Baroch	£22·1
Gangapur	£75
Lower Bhawani	£40

155. The permeability of the impervious soils used in the Maithon and Panchet hill dams (D.V.C.) were:—

Maithon Dam	$2 \cdot 3 \times 10^{-7}$ cm/sec
Panchet Hill Dam	5×10^{-8} cm/sec

156. The prestressed siphon referred to in § 68 was in Chambal Canal, which took off from Kotah Barrage, which itself was a pick-up weir for the water released from the Gandhisagar Dam. The water was not likely to be silt-laden. The construction work of this syphon was in progress and it had yet to be seen if any special siltation problems would arise.

157. The regulation was in the hands of the Government in the case of canals, branches, distributaries, and minors through regulators and head sluices and sluices

fitted with gates. Outlets were provided with reference to the irrigated areas to pass discharge with stipulated duties.

158. Seepage losses in canals lined with tiles or concrete were calculated at 2 cusecs/million sq. ft of wetted area. In unlined canals, the losses were generally taken to be 8 cusecs/million sq. ft of wetted area. Some field observations showed the loss to be between 0·8 to 2·5 cusecs/million sq. ft, including leakage through open joints and evaporation.

159. The percentage of land irrigated by Government and private channels (§ 126) was 40% of the total land irrigated up to 1951. After that year all additional irrigation was provided by Government channels. The total expenditure of £1,280 million could be apportioned approximately as followed:—

Irrigation	£900 million
Power	£325 million
Flood	£55 million

160. Plans were always made to start canal construction simultaneously with the dam or weir and all work was phased in that way. But owing to financial or land acquisition difficulties, the canal construction was sometimes not completed simultaneously with the river structure. There might be a lag of one or more years. The effective potential was counted as created only after the water supply to the fields actually started.

161. Fig. 27 summarized the silt data of Kosi river at Hanumannagar for August and September 1954.

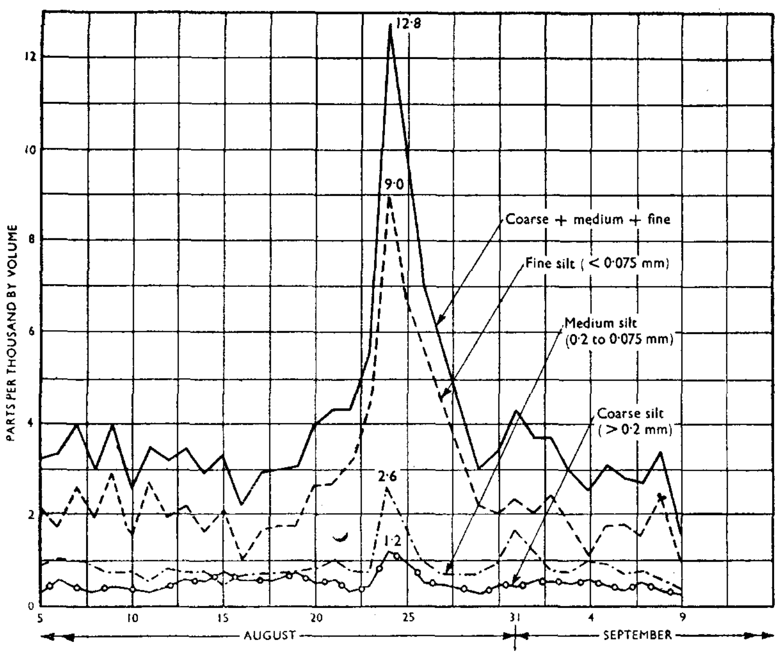


FIG. 27.—KOSI RIVER AT HANUMANNAGAR. SILT DATA FOR AUGUST AND SEPTEMBER 1954

162. Table 9 gave the dead storage and live storage for various dams constructed and under construction in India.

163. In the case of Punjab weirs the retrogression of levels had ranged between 4 ft and 7 ft. The maximum retrogressions observed below some weirs and barrages were:—

Sukkur = 5·0 ft
Islam = 6·9 „
Sulemanki = 8·2 „
Ferozepur = 6·4 „
Trimmu = 4·7 „

TABLE 9.—DEAD AND LIVE STORAGES FOR SOME INDIAN RESERVOIRS

Name of dam	Location	Catch-ment area: sq. miles	Dead storage: acre-feet	Live storage: acre-feet
Krishnarajsagar	Cauvery River, Mysore	4,100	110,000	1,010,000
Mettur	Cauvery River, Madras	16,300	49,633	2,146,465
Muchkundi	Ghatprabha River basin		1,060	13,292
Pathri	Bombay State		506	9,361
Rooty	Krishna basin		1,268	5,330
Pendli Pakala	„ „	115	642	11,777
Dindi	Dindi River, Andhra	1,530	4,224	55,676
Periyar	Periyar River, Madras	232	134,229	225,321
Mopad	Nellore District	250	22,201	48,003
Willingdon	Periyar Odai Nala, Madras	50	0	59,502
Thippayapalem	Ralla Vagucumbum minor basin, Madras	102	7,162	4,178
Darna	Darna River, Bombay	156	24,244	178,212
Nizamsagar	Godavari basin	8,376	94,390	587,660
Maramsilli	Mahanadi basin, Silauria Nala, M.P.	187	2,778	131,267
Kharaung	Kaharung River, M.P.	237	2,295	155,900
Maniari	Khuria, M.P.	310	2,892	119,743
Chankapur	Girna River, Bombay	100	1,918	33,609
Bahoribund	Tapti basin, Jabalpur, M.P.	42	1,998	27,972
Paricha	Betwa River, U.P.	10,384	6,382	67,723
Ghagar Main	Ghagar Nadi, U.P.	110	2,846	120,809
Mala	Sonnala, M.P.	63	2,509	13,671
Rampur	Nagri Nala, M.P.	102		27,513
Bhakra	Sulej River, Punjab		5,600,000	1,820,000
Nagarjunasagar	Krishna River	86,050	3,950,000	5,230,000
Linganamakki	Sharavathy Valley, Mysore	769	90,000	3,500,000
Ukai	Tapti River, Bombay	23,265	950,000	5,250,000
Tawa	M.P.	2,310	175,000	2,786,000
D.V.C. projects:				
1. Tilaiya	Barakar River		60,000	260,000
2. Konar	„ „		49,000	211,000
3. Panchet Hill	Damodar River		148,000	1,060,000
4. Maithon	Barakar River		168,000	1,040,000
Mayurakshi	Masanjor		125,000	365,000
Chambal:				
1. Gandhisagar			620,000	5,730,000
2. Ranapratapsagar			600,000	1,730,000
Hirakud	Mahanadi River, Orissa	32,220	2,050,000	4,510,000

In the case of Islam weir, the retrogression had reached its maximum in the rising stage of 1930 (constructed in 1927), since when there had been more or less continuous accretion, so that by 1941 the recovery was nearly complete at the lower stages. In the case of Sulemanki, the annual rate of recovery was observed to be 0·38 ft. In other cases, the recovery after the initial retrogression was slow.

164. The maximum observed flood in August 1913 was 650,000 cusecs at Rhondia, 10 miles below the site of Durgapur barrage. Flood-routing studies through reservoirs had indicated that the maximum controlled flow at Rhondia would be 460,000 cusecs.

165. Lacey's formula was being used for the design of canals taking off from rivers carrying silt and passing through alluvial plains. In other cases where canals took off from reservoirs, etc., Kennedy-Kutter's formula was generally applied. These formulae had been found to lead to stable sections.

APPENDIX

LIFE OF BHAKRA RESERVOIR

166. *Reservoir characteristics*

Gross capacity:	7,420,000 acre-ft
Dead storage:	1,820,000 „ „
Live storage:	5,600,000 „ „

167. *Annual silt load*

Actual experiments have been carried out for a number of years to determine the annual suspended and colloidal silt load in the river Sutlej. These results show that the average annual suspended and collodial load is 34·5 million tons. No experiments have been carried out to determine the bed load but it has been assumed in the study that bed load would be 15% of suspended and colloidal load.

168. *Average density of silt load*

J. L. Stevens in his papers on silting of Lake Mead and Elephant Butte reservoirs has taken on average density for all types of silt loads as 65 lb/cu. ft. Dr A. N. Khosla has recommended a value of 90 lb/cu. ft. These values are considered to be extremes and the actual value may be somewhere between the two. Studies were carried out for both these densities.

169. *Classification of silt load*

(*a*) Coarse silt (33% of total) will deposit at the head of reservoir, building up the upper delta below full reservoir level.

(*b*) Colloidal silt (10% of total) is assumed to pass out by means of density currents.

(*c*) Medium silt comprises 57% of total. Approximately 8% of this is assumed to pass out by means of density currents. The remainder will first build up deposits above R.L.: 1,680 on the upper delta and the river will take an average slope of 3 ft/mile. After that medium silt will deposit closely in advance of the upper delta and be gradually redistributed by the depletion of the reservoir to form a lower delta in dead storage with an average slope of 1 ft/mile.

170. Working out the advance of the upper and lower deltas on the above basis, the loss of reservoir capacity has been computed for the two studies and Table 10 is an abstract of the results.

TABLE 10

Study No.	No. of years for percentage loss of live capacity of Bhakra reservoir of:				
	10%	25%	50%	75%	100%
1.	45	116	242	368	493
2.	64	155	330	510	678
Average	54	135	286	439	585

References

1. C. C. Inglis, "The behaviour and control of rivers and canals (with the aid of models)". Publications Branch, India House, London.
2. C. C. Inglis, J. S. Reid, and D. V. Joglekar, "Experiments carried out with various designs of piers and sills in connection with the Lloyd Barrage at Sukkur". Bombay P.W.D. Tech. Pap. No. 29 (1929).
3. See ref. 1, chap. 3 of reference 1.
4. Sir Bernard Darley, "The design and construction of the Sarda Canal". Min. Proc. Instn civ. Engrs, vol. 233 (1931–32), p. 140.
5. Gerald Lacey, "Flow in alluvial channels with sandy mobile beds". Proc. Instn civ. Engrs, vol. 9, p. 145 (Feb. 1958).
6. F. F. Haig. "The Emerson Barrage". J. Instn civ. Engrs, vol 17, p. 107 (Dec. 1941).