

INTERIM REPORT
OF THE
ORISSA FLOOD ADVISORY COMMITTEE
1938-39.

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ORISSA FLOOD ADVISORY COMMITTEE, 1938-39.

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Interim Report of the Orissa Flood Advisory Committee of 1938-39.

SECTION I.

INTRODUCTION.

A preliminary report was submitted by the Committee in August last when Mr. A. Vipan, Chief Engineer of Orissa, was on leave and Rai Bahadur Balmokand who was acting for Mr. Vipan served on the Committee. Mr. Vipan has been able to join us in this session.

At an interview with the Hon'ble Minister for Public Works he expressed his opinion that this Committee should consider all possible measures required for flood protection and should not omit to examine other alternatives merely on the ground of cost or jurisdiction.

2. According to a programme of inspections drawn up by Mr. J. Shaw, the Secretary to the Committee and Executive Engineer, Floods and Drainage Division, we inspected some of the areas worst affected by floods in the valleys of the Brahmini, Baitarani and Mahanadi. A diary of inspections is appended (Appendix I).

3. We do not propose to increase unduly the mass of literature that has grown up on the subject of flood control in the Orissa delta by entering into a description of the physical features of the country, the courses of the rivers, the nature of the catchment basins, or the numerous branches into which the rivers break up as they approach the sea, their general behaviour during floods, etc., all of which are fully described in former reports. Some essential particulars of the three main rivers are shown in Appendix VI of this Report and also in the Index Plan.

The comprehensive report of the Orissa Flood Committee of 1928 and the exhaustive, descriptive and analytical report of Professor Mahalanobis with the numerous statistical tables may be chiefly referred to for the above information. We shall have occasion to invite references to particular portions of these reports.

4. Some broad facts are gathered from all these reports, namely, that the three main rivers, Brahmini, Baitarani and Mahanadi have attained a stable regime above the delta and that the maximum discharges there have remained practically the same during the last fifty or sixty years. It has also been recognised that the conditions in the delta being what they are, floods are inevitable.

Of all the previous reports, we have largely made use of the 1928 Flood Committee Report and it may be stated that we are in agreement with that Committee on a number of questions and do not wish to cover the same ground again but only propose to deal with questions of outstanding importance or those on which we differ from them.

5. Generally speaking, while they considered the problem as one of disposal of excess floods, we view it mainly as one of proper distribution and disposal of excess sand.

SECTION II.

GENERAL POLICY AND CONSIDERATION OF ALTERNATIVE MEASURES.

6. There is a widespread belief that if flood embankments were to be removed, the flood waters would deposit their silt in the low-lying lands and then flow away to the sea, causing only slight damage. There appears to be little historical justification for this view. In 1858, before the system of embankments was adopted on a large scale, Captain J. C. Harris wrote :

“ How great have been the vicissitudes to which the Province of Orissa has been subjected ; how vast the amount of suffering and how loud the lamentations of its inhabitants ; how widely proclaimed, and deeply recognized are the necessities of the district ; how much might have been, and how little has been done towards the relief thereof will appear in the sequel, but I would ask, why are these things so in A. D. 1858 ?”

This shows that the subsequent adoption of the policy of embankments has not been the cause of any deterioration. Indeed, conditions have improved since their construction which is borne out by the fact that whereas in 1858 the danger level for the Puri district, measured at Bellevue gauge on the Katjuri at Cuttack, was 21 feet, now it is 23 to 24 feet.

7. If the present embankments were removed floods would at first spill over the river banks, depositing silt along the margins and the banks would steadily rise. After a time, breaches would begin to occur, which would rapidly enlarge, resulting in quantities of coarse silt being deposited in the fields near the breaches, while the finer material would be deposited mostly in fields adjacent to the breaches, where the velocity first decreases, and little would reach the distant low lands.

The existing rivers downstream of the breaches would then begin to silt up with a corresponding increase of discharge through many of the breaches. Some of these would develop into new rivers, which in their turn would breach and so on. In other words, a net-work of ever-changing rivers, loops and breaches would develop, with the inhabitants precariously huddled together even during moderate floods on bits of high ground ; and this would lead to the people constructing isolated private embankments and ring bunds which every one agrees are highly undesirable.

8. The 1928 Flood Committee in paragraphs 16 and 17 of their report wrote :—

16. . . . " It has been calculated that the Mahanadi, the largest of the series, discharges, in maximum flood, about one and a half million cubic feet of water a second where it emerges from the hills above Cuttack, while, if a circle of 25 miles radius be drawn with its centre at that place, the branches of the Mahanadi, where they cross that circle, are capable of carrying only half that volume ; this diminution in discharge capacity is typical of all deltaic rivers. The other half has thus, necessarily, to flow over the surface of the country ; it is the silt in this water which in the ordinary course of nature goes to raise the surrounding land. Artificially to restrict this spill area entails, of course, a deepening of the spill water where no such protection is given and excessive flooding is the result.

17. It must be clearly grasped that, in a deltaic area, there must be flooding ; it is nature's method of land formation, and any efforts to prevent it are doomed to failure from the outset. It might, for example, be suggested that every river should be

embanked on both sides from the point where it leaves the hills to the sea ; the result would merely be that it would deposit silt in its bed, the bed would rise, the floods would rise and the embankments have to be raised to correspond, until eventually these embankments would reach a size at which they could no longer be maintained. They would then burst, probably to the complete destruction of the country in the vicinity which would have been becoming lower and lower relatively to the level of the water in the river."

Up to ten years ago, the view that we must accept natural conditions and cannot control them was held by many hydraulic engineers ; but since Lacey of the United Provinces wrote his paper on "Flow in Channels in Incoherent Alluvium" in 1928, knowledge of the laws governing the flow of water and silt in open channels has made vast strides (see Appendix II). We now realize that the main problem is not so much the disposal of excess water which in the absence of silting presents little difficulty, as the distribution and control of the sand and silt brought down by the rivers. As explained in Appendix II, the quantity of silt which can be carried by a river increases roughly proportionately, to the velocity, and a river of a million cusecs will carry a silt charge of over 2,000 grains per cubic foot of water ; whereas a channel with a discharge of 100 cusecs will carry less than 300 grains per cubic foot. From this it follows that, other things being equal, the larger the channel the greater the silt charge it can carry, so that if rivers are allowed to split up into a network of small channels, they will be able to carry much less silt. It may be said that, if the main rivers of the Orissa delta were each confined to a single channel, they would be capable of carrying their full silt charge to the sea. Where the silt carried by a river is deposited near its mouth, the slope just upstream decreases as the delta advances into the sea ; but owing to the advantage resulting from the littoral drift, the greater part of the silt from the rivers of Madras and Orissa is swept along the coast towards the north, so that the advance of the delta into the sea is relatively slow.

The Krishna and Godavari rivers in the Madras Presidency are embanked and we consider that conditions in Orissa resemble those in Madras much more closely than those existing in Bengal.

9. For the foregoing reasons we hold that the policy should be—

- (i) to conserve and improve the main rivers by a system of adequate embankments, by the provision or maintenance of efficient mouths to the sea so as to enable the rivers to carry their normal flood discharge, for which the available fall is ample;
- (ii) to prevent breaches, which lead to deterioration of the parent river, and
- (iii) to spill water in excess of a predetermined figure on to the land by high-level escapes, so designed as to pass only the finer grades of silt.

10. Two other methods have been suggested for improving flood conditions :

- (a) The diversion of part of the Mahanadi flood-waters over the Banki estate and through a cut in the Daltolah ridge and into the Monaguni river and thence to the Chilka Lake; and
- (b) Detention reservoirs, situated on the tributaries of the main rivers

These proposals are intended to cut off the peaks of abnormal floods.

11. As regards (a), it was stated in our Preliminary Report (Para. 7) that " Mr. Inglis has not yet had time to fully investigate this scheme and will express his considered opinion after doing so." He now agrees that it is problematical whether the " cut " would enlarge naturally to carry 300,000 cusecs; but, if it did, the slope would be so steep— $6\frac{1}{2}$ feet. per mile—that unless controlled at great cost it would swing violently in an effort to lengthen its course and in doing so would devastate large areas and spread a mass of sand and other infertile materials over the country.

We confirm the opinion already expressed that this scheme may be finally abandoned.

12. As regards (b), Detention Reservoirs, in paragraph 8 of our Preliminary Report we suggested that all available records may be examined and rough estimates of cost prepared for the five reservoirs investigated in the past (vide Map V). The Executive Engineer, Floods and Drainage Division, has put up for our consideration a statement of costs and a brief report on the several sites (Appendix IV). His estimates are based on the

cost of the latest *earthen* dam constructed in the same region in the year 1928 across one of the streams with a catchment area of 237 square miles, making such modifications as he thought necessary to suit local conditions. On this basis, the total cost of the reservoirs with an aggregate capacity of 120,000 million cubic feet works out to Rs. 3.6 crores. This amount would have to be increased to Rs. 4.5 crores to provide an adequate storage of 144,000 million cubic feet.

Earthen dams, such as the one across the Karang river, described in Appendix IV, are impracticable in the case of big rivers with which we have to deal. At best, they can be composite dams, the deeper portions being made of stone masonry. We consider that from experience gained elsewhere in India, the cost will not be less than Rs. 500 per million cubic feet of water stored in the case of dams of large storage capacity, and in the case of smaller ones the cost may go up to even Rs. 1,000 per million cubic feet. The total cost is, therefore, likely to be something in the neighbourhood of Rs. 7 or 8 crores.

13. Before estimating in greater detail, the figures of cost, the capacities of various storages and the heights of dams will have to be worked out in order to give optimum flood absorption at minimum cost and thus cut off the peaks of floods to a safe limit. This will necessitate making discharge observations on the various tributaries over a period of years.

As the collection of additional data indicated in Section III of this Report and the investigation of other works recommended by us for the delta area will occupy the whole time of Mr. Shaw and his assistants, it will be necessary, if Government decide to take up this enquiry, to entrust it to another Executive Engineer with an adequate staff. Sir M. Visvesvaraya had, in his note dated 15th November 1937, already recommended the employment of two Executive Engineers for surveys and investigation works connected with the flood problems, but only one has so far been employed.

It may be noted that, in the past, these investigations were confined to reservoirs on the tributaries of the Mahanadi river. The additional Executive Engineer can also examine possible sites in the valleys of the Brahmini and the Baitarani.

14. We are of the opinion that the construction of reservoirs alone would not provide a complete solution. The opinion in America is that no single method can ensure full protection

against floods. In framing a programme of operations we consider that the possibilities of employing cheaper methods should be exhaustively explored and their efficiency tested, before resorting to works of such magnitude as large reservoirs.

15. An estimate of flood damage has been prepared by the Executive Engineer, Floods and Drainage Division (vide Appendix III) and, from the approximate figures given, it seems that the average annual flood damage in the Orissa delta is about Rs. 12 lakhs, during a period of 29 years, from 1910 to 1938 inclusive.

This valuation is only very approximate as official reports of flood damage are not in sufficient detail and various assumptions have had to be made.

These figures include the value of damage to crops, houses, Government flood embankments, and roads, but no allowance for damage to railways is made as there is only very occasional direct damage to them by floods in Orissa and the division of expenditure between ordinary maintenance and flood damage is difficult to obtain from the Bengal-Nagpur Railway Company.

These figures make no allowance for the fact that, although in years of prolonged high floods, cultivators in the low-lying tracts lose their main crop, yet after the flood water subsides, unusually good 'rabi' crops can, in many cases, be grown, while others in more favourably situated tracts benefit from floods. Even allowing for this, the loss to the country on the whole is so heavy as to justify a very much greater expenditure on flood protection than has been incurred in the past.

SECTION III.

COLLECTION OF HYDRAULIC AND OTHER DATA.

16. A very important part of the 1928 Flood Committee Report related to the collection of hydraulic and other data, but systematic action was not taken on their suggestions until a special Floods and Drainage Division was formed in April 1938. During the short period of 8 months at his disposal, Mr. Shaw, the Executive Engineer of this Division, with the aid of his assistants subsequently sanctioned, has been examining and analysing the available data and collecting fresh data on the lines indicated in our preliminary report. As this work was started only recently we find that we are not now in a much

better position than the Committee of 1928. In our Preliminary Report dated August 1938 we made certain tentative recommendations in this matter and we now indicate in greater detail the lines on which the further data may be collected.

A great deal of time and labour has been expended in collecting data in the past, yet much of this has been vitiated as a result of doubtful bench-marks and the impossibility of locating the position of points about which data was collected. The first essential is to carry out an accurate ground-level survey on a triangulated grid system as was done for the Sukkur Barrage Canals in Sind at a cost of approximately one anna and a quarter per acre. (See Sukkur Barrage Canals Completion Report, Volume 3.)

This survey should be carried out over the whole area of the delta, but as a first step it should be confined to the semi-protected and unprotected areas of the main river valleys, viz. the Baitarani, Brahmini and Mahanadi.

Once this is done, with an adequate series of bench-marks, it will be possible at any time in the future to correlate conditions and so get a clear idea of the history of the changes in progress.

17. A plan to a scale of 1"=1 mile should be prepared separately for each river showing where severe attack or appreciable silting is taking place at the present time—siltation being shown in yellow and the scour in blue. A plan should also be prepared of those places where considerable changes have taken place since the early maps of 1843 and 1889 were prepared. This may have to be drawn to a still larger scale to show clearly the three surveys.

18. The lengths of the various channels on the axis of the stream between suitably chosen points and the length between these points on a line passing through the mean position of meanders, and the ratio between these two, should be worked out. This will indicate whether the meanderings have been increasing or decreasing in those lengths.

19. Longitudinal sections based on existing data should now be prepared so far as possible of the main rivers, and when the grid system of levels becomes available this can be corrected and brought up to date. As changes in river regime are dependent to a marked extent on the entry conditions at bifurcations, accurate surveys of restricted lengths of channels just upstream

of these bifurcations should be prepared. Similar surveys are required where a cut-off appears to be developing or any important change is taking place.

20. In the past, high flood level marks have been shown at the anicuts by paint on the masonry. These marks should, after adequate checking, be cut in the masonry so as to preclude the possibility of mistakes occurring.

21. In future work the normal height of each bank should be observed and where levelling is being done, not merely flood levels, but also mean bed-levels at "crossings" between meanders (where the bed is normally flat) should be taken.

22. Cross-sections (position being permanently indicated by masonry pillars) should be taken at selected reaches of each river, say, at the site of anicuts, where they exist, at points of bifurcation, at places where tidal action ceases and at an intermediate reach. These sections should be checked after every big flood and also at the end of the monsoon in each year. For this purpose a Sonic sounding apparatus may be purchased (such as in use at the Hardinge Bridge and the site of the new Brahmaputra Bridge) which enables cross-sections being taken and the depth of scour ascertained even during the highest floods. Automatic gauge recorders may be installed at positions indicated on the accompanying map (Map no. IV.) For the present, four recorders may be purchased so as to save initial expenditure. The system of ordinary gauges may be extended so as to enable readings to be taken at shorter distances and also at all spill-ways where they do not exist at present, and the depths of spillage recorded twice a day during floods.

23. With the aid of the contour map already referred to and the flood levels, the exact extent of land inundated and the depth and periods of inundation will be known.

24. Velocity observations have to be made from time to time where possible with the aid of current meters or other methods, and curves of discharges drawn for each river with reference to the gauges fixed. These curves have to be checked at three or five-year intervals according to observed changes. Where velocity observations are not made, the capacities of the rivers at different reaches where cross-sections are taken, may be determined from the observed flood surface slopes.

25. An automatic water level recorder should be installed in the Brahmini river just above the entrance to the Hansua Creek and discharges of the creek near its head observed by

velocity observations for periods of one month during a spring tide period and also a neap tide period. The salinity of the water should also be observed in the river and the creek by means of a Dionic water tester. The point of importance in this case is to see whether this creek is being maintained as a result of purely tidal action or is being helped by fresh water flow.

26. The river discharges at the anicuts should be calculated, based on the usual formula, by taking suitable longitudinal and cross-sections, allowance being made for approach conditions when the anicut is masked by islands or sand banks. These discharges should be compared with the flow estimated by the slope method.

SECTION IV.

AREAS AFFECTED BY FLOODS BETWEEN THE BAITARANI AND THE BRAHMINI RIVERS.

27. Having indicated in Section II the general policy to be followed in devising measures for flood protection, we now proceed to consider each of the several river systems. In dealing with proposals of this nature they should be taken up from the lower reaches towards the head.

28. Dealing first with the Hansua Creek, the 1928 Flood Committee (para. 118) were of the opinion that the opening up of the Hansua Creek would give the Brahmini a very desirable new and direct outlet to the sea and would probably—

“facilitate the discharge of the Baitarani also, as when the Brahmini floods come down first, they back up the Baitarani water at the junction of the two rivers and thus impede the discharge of the latter.”

We agree that it could be developed, but, if allowed to develop too much it would get out of control and might have most injurious effects on the Dhamra Estuary and the Chandbali Port and it is impossible to foresee what these effects would be without the necessary data.

29. The 1938 Flood Committee attributed the trouble due to flooding above the junction of the Kharsua and Brahmini rivers, to the strengthening and raising of the Gajaria and Uttikan embankments and Damerpur and the Aul Circuit embankments, part of which latter is at present maintained

by Government, and which they said accounted for a raising of the flood water level by certainly 5 feet and possibly considerably more.

The flood levels available were examined and we consider that they do not indicate any such heading up as stated; nor do we believe that these embankments could have any such effect. But here again, the data available is insufficient to enable a final decision to be arrived at, and we recommend that further contemplation of the removal of these embankments should be deferred until the data is available.

The same remark applies to the 1923 Flood Committee's recommendation (para. 123) that the embanked road which crosses the Aul Circuit should be lowered to ground level and maintained only as a fair-weather road. In this connection it is observed that the natural drainage of the country is directed towards the north into the Kharsua river, parallel to the road, and there is no reason to suppose that by lowering the road, conditions will be appreciably improved.

30. Passing up the Kharsua river we come to the Rautra "ghai" on the right bank near Binjharpur. We inspected the site of this breach and the embankment in continuation which is at present being badly threatened. In the event of the Rautra "ghai" being left open there is the risk of the Kharsua deteriorating which it has already commenced to do, as seen from the cross-sections, and this, in our opinion, should not be allowed to continue. We have considered whether it would be better to construct a high level escape at this site, or close the "ghai" and construct the escape at some distance higher up, where there is a more suitable site on the outer curve of the river. The latter alternative is decidedly preferable and we recommend its adoption. The sill level of the escape should be fixed at not more than 5 feet below maximum flood level and its length should be about two-thirds the width of the present Rautra "ghai".

31. On the Pattia at Pahanga village about 2 miles below the Pattia weir there are indications that the river may form a cut-off channel just below a hair-pin loop. This possible development should be carefully watched, as in the event of its taking place there will be a retrogression of levels which might affect the stability of the Pattia weir, and before this occurs the Pattia weir will have to be suitably strengthened. Along with this has to be considered the Brahmini anicut which forms the headwork of the Kharsua and Brahmini systems (vide plan no. VI).

The Brahmini anicut and the Pattia weir are $1\frac{1}{2}$ and $2\frac{1}{2}$ miles, respectively, downstream of the point of bifurcation. The Brahmini anicut was designed with its crest $8\frac{1}{2}$ feet higher than the sill of the masonry crest of the Pattia weir. Making allowance for the difference in distances from the point of bifurcation of the two rivers the Pattia weir may be said to be relatively about 6 feet below the original crest of the Brahmini anicut.

32. The 1928 Flood Committee in paragraphs 103 and 104 of their report stated that :

“ the Brahmini river has lately shown signs of considerable deterioration to such an extent that the greater portion of the weir is now buried in sand and practically the whole supply of the river except in floods, passes down the Pattia.” and

“ this deterioration at the head of the Brahmini delta took place at about the time when the Uttikan and Gajaria embankments in the lower reaches of the river were raised to their present height.”

“ It seems to us very probable that the raising of these embankments, and consequently of the flood level in their vicinity, has, by reducing the surface slope of the river, been a contributory cause of the deterioration higher up.”

We have not been able to ascertain on what evidence the 1928 Flood Committee based their opinion. Elsewhere in this report, when dealing with the Brahmini river, we have recorded our view that after an examination of the flood levels available we consider that they do not indicate that these embankments could have had any considerable local effect. Still less could they effect the head of the Brahmini 55 miles upstream.

Even as early as 1904 Mr. Thompson, the then Superintending Engineer, stated that as far as the Brahmini was concerned the channel was of little use because it was silted up and navigation was maintained with great difficulty.

Before we are in a position to state definitely that the bed of the Brahmini has risen, it is necessary that additional data should be collected.

We, however, agree that the Brahmini Anicut should continue to be removed as and when the structure becomes exposed by floods. Also that the portion of the anicut towards the left bank which has already been lowered should be still further lowered for a short length so as to induce more water down the low level channel.

Whether any useful purpose would be served by substituting regulating gates for the falling shutters on the Pattia weir should be examined with reference to the relative discharges in the two rivers at different stages of flood by means of a model experiment to be conducted at the Research Station at Poona.

33. As regards the Jabra escape, the 1928 Flood Committee recommended that it should be constructed simultaneously with the remodelling of the Pattia weir. The escape, however, has come into being before any steps were taken to remodel the Pattia weir and it has had the effect of reducing the flood discharge below it to the detriment of the Brahmini river. We recommend that the crest should be raised to R.L. 66'00.

SECTION V.

AREAS AFFECTED BY FLOODS BETWEEN THE MAHANADI RIVER AND ITS BRANCHES.

34. We are in agreement with the recommendations of the 1928 Flood Committee regarding the area between the Kendrapara and Machgaon Canals contained in paragraphs 136 to 140 of their report.

35. It is observed that the Katjuri-Debi river seems to be striving to move sideways to the south-west by scouring its banks and developing its western channels. This is a process which it is very difficult to stop, so gradual movement in this direction may be anticipated.

36. In the Kakatpur-Prachi-Kadua areas which are badly affected by floods, we reiterate the remarks of the 1928 Flood Committee in paragraph 152 of their Report that it is necessary to carry out a special survey and investigation of this tract. Here it may be noted that in the 1928 Flood Committee Report a proposal was made to convert the Prachi into a more efficient drainage source. We agree that everything should be done to improve the drainage courses wherever possible, but we consider that owing to the comparatively high level of the Prachi bed, except in its lower reaches, very little development can be expected and no great relief can be looked for by this procedure.

The only proposal we have to make for the present to give partial relief to the Kakatpur area is to investigate the possibility of a retired embankment set well back from the river margin and located adjacent to the higher and thickly populated ridge of land running in a south-easterly direction from Hasanpur to Lataharan. This will form a connecting link between the Government embankments 1B and 2B.

The breaches in the embankment 2B may be closed temporarily.

37. The Katjuri loop has been deteriorating and the Surua loop developing for a very long time so much so that there is hardly any flow in the Katjuri until there is about 12 feet depth of flow in the Surua. In our opinion this deterioration has gone too far to be reversed except at great cost. This means that the Surua will continue to enlarge and this position must be accepted. Here again, more data is required to give an authoritative opinion, but looking forward to the further scour of the banks of the Surua the policy to be followed should be to retire the embankments where necessary.

In this case it is very important that adequate embankments should be properly maintained.

38. In the central Puri district what is aimed at is an equitable distribution of the waters of the Bhargovi, Dhanua and Kusbhadra rivers in accordance with their carrying capacities. The Bhargovi river has no direct outlet to the sea, but passes eventually into the Chilka Lake, after discharging a considerable portion of its flood volume into the Kanchi and Naya Nadi.

The Dhauria river takes off from the Kanchi and passes directly into the Samang Pat, the smaller share of flood-water continuing down the Kanchi to the Sur Lake (*vide* Index Map).

The flood carrying capacity of the Bhargovi is slowly deteriorating and will continue to do so unless a more direct outlet to the sea is provided for the flood-water; and it is only by this means that conditions in the area to the east of the Chilka Lake can be improved. This direct outlet should, in our opinion, take the form of a low level escape in the left bank of the Bhargovi, situated at about 2 miles above the Kanchi off-take and a channel leading from it to the Sur Lake.

It has been found that the Sur Lake Sea Cut has remained open even with the present small discharge, and so this cut, in combination with the flood-water received from the proposed

escape offers the best exit for the Bhargovi flood to the sea. With this outlet the Bhargovi river should be improved by judicious control of the water passing down the river below and by a gradual reduction of the spill over the Achutpur escape upstream. This spillway channel from the Bhargovi to the Sur Lake should be double embanked, the banks being so spaced as to be ultimately capable of carrying the full discharge of the Bhargovi. The discharge at the head of this channel will, during the period of development, have to be controlled in order to prevent undue erosion during the early stages of its development.

39. As a result of the gradual improvement of the Bhargovi the discharge entering the Daya will go on decreasing. This, combined with the policy of maintaining the embankments to an adequate section and the gradual reduction of spills from the head downwards, will, in the process of time, result in the improvement of flood conditions in the area on the east shores of the Chilka Lake. Until this improvement of the Bhargovi river takes place there is no purpose served in repairing the existing breaches in the lower reaches of the Daya river.

The Nuna or Salt Embankment on the east of the Chilka Lake should be maintained in an efficient condition and suitable arrangements made to permit of flood-water passing into the lake and to exclude the inundation by salt water from the lake when the flood subsides.

40. The Flood Committee of 1928 in paragraph 159 of their Report referred to the possibilities for the drainage of the Sur Lake by means of a cut to the sea. They were of the opinion that this work seemed to afford the key to the whole trouble in Central Puri. Acting on the above recommendation the work has been carried out and access to the sea has been established.

The leading channel from the lake to the sea has not, however, developed to the extent that we would like to have seen, owing, it is believed, to the presence of a particularly objectionable kind of weed which grows in profusion along its bed. We recommend that this should be removed as far as possible by ploughing before each flood season and the channel capacity increased from the Sur Lake down to the sea. With the removal of the weeds and the improvement of the cut we anticipate that a considerable scouring action will take place.

In view of the fact that a large area of *dalua* paddy is grown both in the Sur Lake and in the Samang Pat with which it is undesirable to interfere, we suggest that for the time being

a temporary earthen bund, if required, could be erected across the cut at the end of each flood season which should be removed with the approach of the monsoon.

When the development of the cut takes place a drowned sill can be constructed to replace the temporary earthen bund in the interests of the dalua paddy cultivation.

41. The Dhanua is the main drainage of the Bhargovi-Kusbhadra doab and takes most of the escape spill and drainage of this area directly into the Kusbhadra and also in high flood into the Dal Nadi and so to the Sur Lake. It is most desirable that the Kusbhadra should be confined to its own channel and mouth. We consider that with the improvement of the Sur Lake Sea Cut, the Dhanua and the drainage of the Bhargovi-Kusbhadra doab should be assisted to flow into the Sur Lake; and the Dal Nadi which connects the Kusbhadra and the Sur Lake should be closed by an earthen embankment.

As stated by the 1928 Flood Committee, the drainage of the Dhanua basin is very largely obstructed by private embankments. We regard their removal at present as premature, but with the improvement of the drainage facilities in this area by the means we have advocated, these embankments will become superfluous and their removal will follow automatically.

42. The Kusbhadra river mouth continues to function irregularly and we consider it best that the present policy should be followed, of watching the conditions carefully and in the event of closure or partial closure of the mouth, making a leading cut just before the monsoon, which will enable it to develop again with the first freshet.

43. The Kusbhadra river is divided for a few miles into two divergent channels near Nagpur. The Dhanua and Dal Nadi are connected with the western loop. The eastern loop is at present deteriorating. Investigations should be made as to which channel should be improved to act as the main one so that the other may be closed.

Below Banamalipur the Kusbhadra is generally embanked only on its right bank and several large spills take place even in ordinary floods over the left bank into the Prachi-Kadua area. Further investigation is required regarding the capacity of the river, but in the meantime, we recommend that low-level spillways should be stopped as undesirable from the hydraulic view-point.

44. The Jogisahi escape on the Kusbhadra river was inspected and we understand that this escape is generally damaged during high floods and in 1937 the centre portion of the body wall breached. This portion has since been temporarily reconstructed with its crest 3 feet lower than its original level. The question has been raised as to whether this escape should be rebuilt permanently at its present site or shifted to a more favourable situation. It might have been better if it had been located about 200 feet further upstream, but at the same time we consider that the damage to the weir is due, not so much to its position as to its design. If suitably designed we see no objection to rebuilding it to the original crest level at the present site.

45. As regards the Pipli-Nimapara road, we do not think that the level of the road should be lowered, as means of proper communications are so badly needed in this area. It would be sufficient to provide vented causeways so that obstruction to the free flow of flood-water is reduced to a minimum.

The Jagannath road was breached at two places above Baliauta in the 1937 flood when the flood level was about 2 feet lower than the road surface. We are of the opinion that the breach nearest Baliauta may be closed and that, near the original bridge site above, a high-level causeway may be constructed instead of leaving the breach open.

46. The Mancheswar gap over which there is a large flood spill between the Kuakhai right embankment and the Bengal-Nagpur Railway embankment should, until the river channels below show definite signs of improvement, be left at its present width and the existing three breaches in the Kuakhai right embankment be closed to a height of 2 feet less than the crest of the existing embankment. This will act as a breaching section in the case of an abnormal flood.

47. Having dealt with the area affected by the Mahanadi and its branches from the sea upwards, we now proceed to consider the conditions at the head of the system.

The full flood of the Mahanadi passes through a narrow gorge at Naraj and thereafter bifurcates, a part, nearly half during high floods, passing over the Naraj weir on the right bank into the Katjuri and the remainder flowing on down the main Mahanadi channel, to pass over the Mahanadi Anicut. About $2\frac{1}{2}$ miles below the Naraj weir the Katjuri spills extensively into the Mahanadi in the gap between the dividing embankment and the Biranassi spur embankment.

Regarding the Naraj weir the 1928 Flood Committee have observed that :

“The work as at present constructed gives an adequate measure of control over the discharges to be passed to each branch during low stages of the river, while at high stages after control is lost it automatically ensures an equitable distribution between them.”

An examination of the river gauges since 1928 confirms the above view so far as the distribution of water is concerned (vide Prof. P. C. Mahalanobis' Report Proof pages 81 and 82). There appears to be little doubt that the Katjuri is receiving more than its fair share of silt. To remedy this it may be desirable to modify the approach conditions, but before a definite opinion can be expressed in regard to this, it is necessary to collect further data. Our colleague Mr. Inglis states that the question of silt distribution between these two rivers could be clearly demonstrated and studied by means of a model experiment. This investigation which would have to be conducted at the Research Station at Poona has a most important bearing on the possibilities of the improvement of the Katjuri river system which at present so adversely affects the Puri district and we recommend that this be done.

The development of spill channels in the Biranassi gap referred to above may also be watched, as at present.

During very high floods the Katjuri river spills over the Banki road on its right bank for a length of about two miles and this acts as a safety spillway for keeping down the highest flood levels round Cuttack town on the Katjuri side.

SECTION VI.

SUMMARY.

48. We shall now summarise our recommendations under three heads, namely :—

- (i) Those that relate to the whole delta area;
- (ii) Those that apply to the area lying between the Baitarani and Brahmini; and
- (iii) Those that apply to the area traversed by the Mahanadi and its branches.

49. (i) Taking the first of the above, we recommend—

(1) That the policy to be followed for flood protection in the delta should be the improvement of main rivers by—

(a) the control of the discharges and the silt charges at the bifurcations of the rivers (paragraphs 8 and 9),

(b) providing better outlets to the sea (paragraph 9),

(c) adequately strengthening the embankments and preventing breaches both in embankments and in the natural banks ; (paragraph 9), and

(d) the provision of high level escapes (paragraph 9).

The above process has to be spread over a long period of time, conditions being modified so that the rivers will naturally improve their discharging capacities from the head of the delta to the sea ;

(2) That the scheme for diverting a portion of the Mahanadi floods through a deep cut across the Daltolah ridge to the Monaguni river and valley and thence to the Chilka lake be finally abandoned (paragraph 11);

(3) That the question of detention or storage reservoirs be only taken up for investigation after other cheaper methods have been tried and their results are known (paragraphs 12 to 14);

(4) That judging from the loss caused to the country by flood damage Government would be justified in spending a much larger amount than has been incurred in the past on flood protection (paragraph 15); and

(5) That hydraulic and other data be collected in the manner indicated in Section III of this report (paragraphs 16 to 26).

50. (ii) Under the second head the following are our recommendations :—

(1) That necessary data be collected for deciding how far the development of the Hansua Creek may be allowed without injuriously affecting the Dhamra estuary (paragraphs 25 and 28) ;

- (2) That further contemplation of the removal of the Damerpur, Gajaria and Uttikan embankments should be deferred until the required data is available (paragraph 29);
- (3) That no appreciable improvement of the drainage conditions can be expected by lowering the road across the Aul Circuit (paragraph 29);
- (4) That the Rautra "ghai" be closed and a high level escape at some distance higher up be constructed on the outer curve of the river (paragraph 30);
- (5) That the removal of the Brahmini anicut be continued as and when the structure becomes exposed by floods (paragraph 32);
- (6) That the utility of substituting regulating gates for the falling shutters on the Paltia weir be examined by means of a model experiment at the Poona Research Station (paragraph 32) and
- (7) That the Jabra escape crest level be raised to R.L. 66.00 (paragraph 33).

51. (iii) Our recommendations in respect of the area affected by the Mahanadi and its branches are:—

- (1) That a special survey and investigation be made of the Kakatpur-Kadua-Prachi area (paragraph 36);
- (2) That partial relief may be given to the Kakatpur area by a retired embankment set well back from the river margin from Hasapur to Lataharan, connecting Government embankments 1B and 2B (paragraph 36);
- (3) That the breaches in the embankment No. 2B may be closed temporarily (paragraph 36);
- (4) That as the deterioration of the Katjuri and the development of the Surua have gone too far to be stopped except at great cost, and until further data is available, the embankments along the Surua right bank should be retired where necessary and adequate embankments should be properly maintained (paragraph 37);

- (5) That the Sur Lake Sea Cut be deepened by ploughing up the bed before each monsoon season, by uprooting the grass and weeds and that a masonry sill be provided at a suitable level to prevent salt water ingress into the lake (paragraph 40);
- (6) That a direct connection to the sea through the Sur Lake be given to the Bhargavi river by means of an escape at about 2 miles above the Kanchi off-take and a channel therefrom to the Sur Lake (paragraph 38);
- (7) That the Nuna embankment near the Chilka Lake be maintained in an efficient condition with arrangements for passing off flood water and keeping out salt water (paragraph 39);
- (8) That the Dhanua be assisted to flow into the Sur Lake and the connection between the Dal Nadi and the Kusbhadra be closed by an earthen bund (paragraph 41);
- (9) That the private embankments in the Dhanua basin be not interfered with until the drainage facilities recommended have been provided (paragraph 41);
- (10) That vented high level causeways be provided for the Pipli-Nimapara road and the road level be not lowered below its present height (paragraph 45);
- (11) That investigation be made for deciding which of the two loops of the Kusbhadra near Nagpur may be developed; (paragraph 43);
- (12) That the low level breaches near Banamalipur be closed until further investigations are made (paragraph 43);
- (13) That the Jogisahi escape be redesigned and reconstructed at its original crest level (paragraph 44);
- (14) That at the bridge site on the Jagannath Road where a breach occurred in the 1937 floods, a vented high-level causeway be constructed, the other breach near Baliana being closed (paragraph 45);
- (15) That the Mancheswar gap be left at its present width, the breaches in the Government embankment nearby being closed upto 2 feet below the top of the existing embankment (paragraph 46) and

- (16) That a model experiment be conducted at the Poona Research Station about the question of silt distribution between the Katjuri and the Mahanadi at Naraj, the experiment to include the reach where the Surua takes off from the Katjuri (paragraph 47).

SECTION VII.

CONCLUSION.

52. In dealing with deltaic flood problems it cannot be anticipated that finality can be reached. Full investigations have to be made and all necessary data, such as those indicated by us, and more, have to be collected. Some of these operations will have to be repeated at regular intervals under proper supervision and accurate records maintained, so that a continuous history of the conditions in the delta may be available for evolving suitable measures from time to time. Particular care should be exercised in safeguarding these records and they should, we consider, be placed in the special custody of one particular officer who will be responsible for their safety.

Until the investigations suggested by us have been made, we shall not be in a position to draw up a programme of works of a long range character.

In framing our present recommendations we have assumed that in an agricultural tract like the Orissa delta only partial but not complete relief should be aimed at, the success of such relief being tested by the ability and the rapidity with which the farmers can rehabilitate themselves after an occasional crop loss.

We wish to place on record our appreciation of the services of our Secretary Mr. J. Shaw, who has rendered us valuable assistance in the preparation of this report.

M. G. RANGAIYA.

C. C. INGLIS.

A. VIPAN.

The 23rd January 1939.

APPENDIX I.

DIARY OF TOURS.

January 9th, 1939.—Cuttack to Jenapur. Inspected the Mahanadi and Berupa anicuts, the Brahmini river from Dharmala to Jenapur, Kuaria and Mattaganjar aqueducts, the Brahmini river and Pingua embankment to 1 mile upstream of the railway bridge and also half of the Brahmini anicut.

January 10th.—Jenapur to Akhuapada and Jajpur. Inspected the Brahmini anicut, Jabra escape, the Pattia river and anicut, the Pattia at Pahanga, the Pattia-Kharsua at the Orissa Trunk Road crossing and the Baitarini and Burrah anicuts and bifurcation.

January 11th.—Akhuapada and Jajpur to Aul. Inspected *en route* the Kharsua-Burha river junction at Kama'pur, the Kharsua at Binjharpur, Rautra ghai and the Kharsua river from Singhpur to Aul.

January 12th.—Aul to Cuttack via Pattamundai. Inspected the lower portion of the Kharsua and Brahmini rivers; Hansua creek head, Gajaria and Uttikan embankments, Damerpur and Aul Circuit Embankments and the river and Aul embankment for 3 miles upstream of Alha.

January 13th.—Halt at Cuttack.

January 14th.—Cuttack to Naraj and back. Inspected the Katjuri and Kuakhai river heads, Naraj anicut and the Mahanadi at Naraj.

January 15th.—Halt at Cuttack.

January 16th.—Cuttack to Pipli via Sardeiptr and Baliana. Inspected the Barang river bridges, heads of Kusbhadra, Bhargovi and Daya rivers, the Jagannath road brach above Baliana, Jogisabi and Kanti flood escapes and the Dhanua river and country on the Nimajara road.

January 17th.—Pipli to Puri. Inspected the heads of the Kanchi and Dbauria rivers, the Atharnala, the Samang Pat area and the Sunamuhi head.

January 18th.—Halt at Puri.

January 19th.—Puri to Cuttack.

January 21st.—Inspected the Katjuri river near Cuttack and the Surua-Katjuri bifurcation.

APPENDIX II.

NOTE BY C. C. INGLIS, DIRECTOR, CENTRAL IRRIGATION AND HYDRODYNAMIC RESEARCH STATION, POONA, ON "OUR PRESENT KNOWLEDGE REGARDING THE FACTORS AFFECTING SILTING AND SCOURING OF CHANNELS".

Since 1928, when the previous Orissa Flood Committee wrote their report, marked advances have taken place in our knowledge of the flow of water in open channels. In 1928, Gerald Lacey, at that time Research Officer (U.P., P.W.D.), wrote his paper on "Stable Channels in Alluvium".* The formulas in that paper derived for regime channels, re-stated in terms of discharge and a bed-silt factor, were as under:—

$$f = 1.6 \sqrt{m}$$

$$P = 2.67 Q^{\frac{1}{2}}$$

$$R = .47 (Q/f)^{\frac{1}{2}}$$

$$A = 1.25 \frac{Q^{\frac{5}{2}}}{f^{\frac{1}{2}}}$$

$$V = .8 Q^{\frac{1}{2}} f^{\frac{1}{2}}$$

$$S = .00054 \frac{f^{\frac{5}{2}}}{Q^{\frac{1}{2}}}$$

$$V = \frac{1.3458}{N_a} R^{\frac{1}{2}} S^{\frac{1}{2}}$$

Where

f = bed silt factor.

d = mean diameter of silt particles in inches.

m = do. in millimetres.

Q = discharge.

P = wetted perimeter.

R = Hydraulic mean depth.

A = PR = area of section.

V = mean velocity.

S = energy gradient (=slope in regime).

N_a = a constant rugosity factor.

These formulas (except the last, which is a general formula) pertain only to channels flowing with a constant discharge in incoherent alluvium, and are not directly applicable to non-regime conditions.

No formulas have as yet been established for non-regime conditions, and the factors affecting non-regime flow, including rate of change of discharge of water and its dependent variables (rate of scour and silt movement) are so complex as to be almost impossible to enunciate; so we are forced to adopt model experiments for solving non-regime

* Paper 4736 Instt. of Civil Engineers, Vol. 229, Part I, 1929-30.

problems. Model experiments carried out at the Central Irrigation and Hydrodynamic Research Station at Poona show that models carrying discharges of more than 4 cusecs follow the relation—

$$P_m/P_p \propto \sqrt{Q_m/Q_p}$$

(where suffix m refers to model and p to prototype) and $R_m/R_p \propto \sqrt[3]{Q_m/Q_p}$ very approximately.

The question of slope relationship is more complicated, in that not merely silt grain size but also shock losses have to be taken into account but where shock losses are similar

$$S \propto \frac{f^{5/3}}{q^{1/3}} \text{ where } q = \text{discharge per ft. of perimeter.}$$

These equations, it must be clearly understood, apply to channels with *similar conditions but different discharges*. In a channel in which the discharge varies, the channel obviously cannot alter its slope, width, and depth, whenever the discharge changes; but it will tend to do so; and each channel is the integrated effect of all the various discharges which have flowed. The banks of channels being more resistant to scour than the bed, the biggest changes take place in the bed and it is a well-established fact that after low floods the beds of rivers rise, to be scoured out again in the next high flood. This scour is not due solely to side resistance (flume flow); but even more to the fact that the silt charge increases directly as the effective velocity, and hence as the discharge increases the silt per c ft. of water also increases and is about 10 times as great in a channel carrying 1,000,000 cusecs as in one carrying 100 cusecs.

The practical application of this to the Orissa delta is that the more the channels are allowed to split up, the less the quantity of sand that can be carried.

In channels with widely fluctuating discharges and silt charges, there is a tendency for silt to deposit at one bank and for the river to move to the other bank. This is the origin of meandering.

A recent analysis of available data † has shown that both the length of meander (on the axis of a stream) and its amplitude (or meander width) vary very approximately as the square root of the maximum discharge—so that if the discharge of one river is 4 times that of another, the length and amplitude of a meander are twice as great. This also holds for wetted perimeter; so that meanders vary according to the linear scale and are almost identical in plan, for similar conditions, irrespective of scale.

† Central Irrigation and Hydrodynamic Research Station Technical Note No. 12 of June 19:8 on "Relationship between meander belts, distance between meanders on axis of stream, width and discharges of rivers in flood plain and of incised rivers" by C. C. Inglis

Experience shows that the amplitude of a meander is markedly affected by slope, and hoading-up at a weir increases meandering, especially where the river bed consists of fine material. While the discharge of a river is increasing, there is a tendency for the meanders to increase in length and hence to erode the concave bends at their downstream ends. This cutting is highly complex in character; but there is a tendency for a river bend to move downstream, though this is often masked by cut-offs, resistant strata, etc.

Owing to changes in sinuosity, a point which at one time was situated at the outside of a curve may later become the inside of a curve. This change is generally gradual, but may occur suddenly and in a few cases what was the outside of a curve in normal floods may become the inside in a maximum flood and again become the outside on a falling flood.

From the above it will be clear that over a long period of years conditions will tend to change at a bifurcation, and the branch which originally took off from the outside of a bend may, in the course of time, draw water as though from the inside of a bend. This affects the discharge of water only to a small extent but has a very marked effect on the quantity of silt drawn; because whereas a channel taking off from the outside of a bend draws high velocity top-water, which is relatively free of bed silt, the channel taking off from the inside of a bend draws a large proportion of low-velocity bed-water, containing a large proportion of bed silt (‡) and this will occur even though a high sill be constructed across the entrance.

At a bifurcation, therefore, the channel taking off from the outside of a bend takes more water and much less silt than had the approach been straight, while the channel taking off from the inside of the bend gets a little less water and much more silt. As a result, the outer channel—other things being equal—tends to increase in discharge and deepen, while the inner channel, unable to carry its excess silt burden, silts its bed with coarse silt and sand. The Brahmini at its head is an example of this.

Once deterioration has set in, it is difficult to revive a channel, partly because of the coarse sand deposited on its bed but also because the channel has become unnatural in shape, being much too wide relative to its depth, such a river will not revive except by becoming, in the first instance, a small, natural, river which may, if conditions are exceptionally favourable, again expand. For this to occur, the channel must be allowed to scour its bed to a considerable depth where the new channel is being re-born, and for this reason it has been proposed that the Brahmini anicut, which has already been removed to a depth of 6 feet at the left flank of the river, should be removed to a still greater depth.

‡ Bombay P.W.D., T. P., no. 52 "Factors affecting exclusion of bed silt from canals".

Bombay P.W.D., T.P., no. 59 "Silt control at Heads of canals and Distributaries - by C. C. Inglis and D.V. Joglekar".

From the above discussion it is clear that a single channel is much more efficient as a permanent silt carrier than the two branches below a bifurcation. The policy, therefore, should be to prevent new channels opening and to allow old, dying channels to close. Where, however, it is necessary to maintain both the rivers at a bifurcation, steps should be taken to maintain constant conditions; because there is only a certain amount of energy available for carrying silt to the sea and every variation from optimum distribution of silt relative to the water, amounts to a partial deterioration of the system considered as a whole.

Before leaving this question of silt-carrying capacity, the effect of 'detention reservoirs' will be considered. As already stated, it is well known that sand accumulates in the beds of rivers after years of low floods and that the rivers are purged of these large quantities of accumulated silt when a large flood occurs. It might, therefore, seem at first sight that if the peaks of floods were cut off by detention reservoirs, the river would deteriorate. It is true that the beds of rivers might rise, but this would be because the channels would alter to carry the smaller maximum discharge; and though the maximum capacity of the rivers for carrying silt would be reduced, the amount of sand coming down the river would not merely be correspondingly reduced but would be stopped almost altogether from the tributaries on which the reservoirs were constructed.

Furthermore, though the peak of the flood would be decreased, the period of flood would be correspondingly increased and hence a considerable quantity of silt would be carried for a greater proportion of the year. The degree of fluctuation of discharge of water and silt would also be decreased; and as this is the chief cause of meandering there is every reason to believe that though the smaller channels would require more slope, they would obtain this by straightening their courses with a corresponding decrease of silt trouble.

APPENDIX III.

EVALUATION OF FLOOD DAMAGE.

Flood damage is considered under four groups—

1. Crops, houses, livestock, personal property and land.
2. Flood embankments and protection works.
3. Roads and bridges.
4. Railways.

No account of remission of taxes or gratuitous relief is included as the original loss is what is required.

Regarding group 1, the Collectors' flood reports for the bad flood years of 1933 and 1937 are selected as giving more detailed descriptions and figures of damage.

Group 2 is arrived at by consideration of the Public Works Department Annual Embankment Reports.

Group 3 comprises the District Board figures of flood damage expenditure.

Under group 4, it is difficult to get detailed figures as flood damage to railways in Orissa is in general small and casual, and it is only catastrophes such as the Baitarani flood of 1927 which are really damaging. The loss is also not directly provincial. Flood damage losses to the Railways are, therefore, omitted from the present estimate. For information it may be noted that repairs and improvement to the Brahmini bridge flanking spurs in 1920 cost Rs. 86,000 and in 1929-31 Rs. 37,300 were spent in protection from scour of the foundation wells. Rs. 5,81,278 were spent in renewing the track after the 1927 flood of the Baitarani and Rs. 1,99,887 in providing extra waterway.

Methods of classification and evaluation are available in a fuller report.

Rough valuation of the flood damage losses is as follows, based on the 1937 and 1933 figures with roughly comparative allowance for the other years of bad flood damage in Orissa :—

				Rs.
1937...	House damage	...	...	29,000
	Crop damage	...	...	28,62,000
	Public Works Department	...	...	59,000
	Roads, etc.	...	...	13,000
			Total	...
				<u>29,63,000, say Rs. 29.5 lakhs.</u>
1933...	House damage	...	...	1,05,000
	Crop damage	...	...	53,95,000
	Public Works Department	...	...	56,000
	Roads, etc.	...	...	37,000
			Total	...
				<u>55,98,000, say Rs. 56 lakhs.</u>

C. O. say 85.5 lakhs.

						B. F. say Rs. 85.5 lakhs.	
1919	...	...	...	...	...	20	..
1927	...	...	...	...	...	95	..
1926	...	...	...	...	...	60	..
1925	...	...	...	...	...	23	..
1920	...	...	...	...	...	29	..
1919	...	...	...	...	...	66	..
1911	...	...	...	...	...	80	..
Total						...	348.5 lakhs.
						<u>say Rs. 849 lakhs.</u>	

Say Rs. 349 lakhs from 1910 to 1938, i.e., a period of 29 years inclusive. The average annual losses from flood damage therefore amount to Rs. 12 lakhs.

These figures are only very approximate as the information available is not in sufficient detail and various assumptions had to be made. Also it has not been possible to differentiate the damage under each river and tract.

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Executive Engineer,
Floods and Drainage Division Cuttack.

APPENDIX IV.

DETAILS AND COST OF RESERVOIRS.

(See Map V.)

Name of river.	Site and situation of dam.	Catchment area sq. miles.	Area submerged at full reservoir level square miles.	Capacity of reservoir million cft.	Height and length of dams in feet.	Approximate cost in lakhs of rupees based on 3:1 earthen slopes and the Karang Reservoir.			Cost per million cubic feet in rupees.
						Land.	Dam and works.	Total.	
Karang ...	Existing in Central Provinces 15 miles north of Bilaspur.	196	14.7	6,781	1,320 at 60	3.5	12.5	16	237
1. Tel ...	Gantapara 29 miles upstream of Sonapur.	7,760	50	50,000	3,000 at 113 2,000 at 60 1,224 at 50	13	134	147	293
2. Ib. ...	Rampur, 30 miles upstream.	3,267	64	11,500	1,200 at 14 1,254 at 42 858 at 71 2,178 at 94.6 1,716 at 22	12	43.5	55.5	482
3. Mand...	Deyjari, 30 miles upstream.	1,854	45.5	10,000	7,120 at 65	10	78.5	88.5	443
4. Hasdo...	Kandygat, 59 miles upstream.	3,011	17.67	5,900	800 at 100 750 at 12	4	21.5	25.5	482
5. Jonk ...	Maharoli, 16 miles upstream.	1,333	29.37	43,000	1,542 at 93 average 173 maximum.	7	37	44	102
Total ...		17,215	196.5	120,400	360.5	...

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Executive Engineer,

Floods and Drainage Division, Cuttack.

APPENDIX V.

APPEN
STATISTICS OF POPULATION,
(See Map)

District, Subdivision and Revenue Thana.	Area in square miles.	Townsh.	Villages.	Homes.	Persons.		Persons per square mile.		Cropped area (acres).
					1931.	1921.	1931.	1921.	
1	2	3	4	5	6	7	8	9	10
CUTTACK ...	3,654	3	5,506	456,507	2,176,707	2,004,678	596	585	1,322,193
SADR SUBDIVISION ...	1,562	1	2,526	230,511	1,037,591	1,043,301	697	668	876,451
Cuttack ...	298	1	362	49,226	237,148	214,572	796	521	88,877
Banki ...	198	...	149	17,451	184,406	70,110	426	854	55,981
Salepur ...	303	...	605	60,467	266,449	289,245	879	155	121,140
Jagatsingpur ...	372	...	694	63,549	306,497	287,526	624	773	171,363
Tirtol ...	391	...	716	89,818	193,491	181,549	495	464	136,650
KENDRAPARA SUBDIVISION	977	1	1,353	98,625	496,498	478,773	508	410	374,584
Kendrapara ...	301	1	597	49,882	248,060	249,369	824	828	148,604
Patamundai ...	302	...	264	25,312	127,112	120,707	421	400	104,925
Aul or Rajbari ...	374	...	472	23,431	121,317	108,697	324	291	121,155
JAJPUR SUBDIVISION ...	1,115	1	1,627	127,371	532,218	512,604	531	487	371,158
Jajpur ...	320	1	610	60,632	281,789	259,377	881	811	153,214
Dhatamsala ...	795	...	1,017	66,739	310,429	253,227	390	326	217,864
BALASORE ...	2,065	2	3,479	214,945	990,010	1,80,534	482	410	523,353
BHADRAK SUBDIVISION...	914	1	1,238	97,399	448,771	438,691	49	452	405,967
Bhadrak ...	283	1	439	39,426	171,884	181,841	597	623	140,297
Basuichpur ...	190	...	219	15,973	78,757	71,026	415	510	80,512
Dhamnagar ...	230	...	325	28,842	133,711	129,056	591	559	107,230
Chandball... ..	206	...	255	13,158	62,419	56,078	314	266	76,728
SADR SUBDIVISION ...	1,151	1	2,241	117,546	543,829	541,903	474	461	518,292
Soro ✓ ...	403	...	817	43,462	191,755	218,633	479	644	198,973
Balasore ...	226	1	395	24,883	111,759	102,364	495	451	94,636
Jaleswar ...	137	...	179	12,011	56,899	53,027	425	366	65,775
Baliapal ...	206	...	470	21,398	108,107	103,106	525	484	69,104
Basta ...	182	...	380	15,792	75,309	67,773	414	366	79,834
PURI ...	2,492	1	2,987	213,167	1,035,154	951,651	415	392	760,741
SADR SUBDIVISION ...	1,521	1	1,830	131,529	657,625	614,754	432	401	469,131
Puri ...	858	1	653	51,024	255,821	242,190	298	292	188,162
Gop ...	288	...	439	22,158	128,914	110,337	448	383	97,599
Pipil ...	375	...	738	57,547	272,890	262,227	728	699	183,420
KHURDA SUBDIVISION ...	971	...	1,157	81,638	377,629	336,897	389	347	291,500
Khurda ...	605	...	712	58,056	262,660	237,727	434	393	...
Bandpur ...	366	...	445	23,582	114,969	99,170	314	271	...

APPENDIX VI.

DETAILS OF THE THREE MAIN RIVERS OF ORISSA—THEIR DELTAS AND FLOODS, ETC.
(See Map II.)

		Mahanadi.	Brahmini.	Baitarani.
1. Total length of river	... Miles	538	488	216
2. River length from the source to head of delta.	Miles	466	345	156
3. Catchment area at head of delta	... Square miles	51,000	14,000	4,000
4. Total average rainfall in catchment from July to September.				
	(a) Maximum ...	52.6"	54.9"	49.7
	(b) Minimum ...	26.7"	19.3"	15.6
	(c) Average ...	31.6"	36.9"	32.1
5. Discharge at head of delta (In Cusecs).				
	(a) Maximum ...	15,71,000	6,43,290	5,00,000
	(b) Minimum ...	200	190	7
6. Total area of delta (within outside boundaries).	... Square miles	2,940	854	65
7. Protected area served by canals	... Square miles	641	62	19
8. Area protected by embankments but not irrigated.	Do.	456	166	10
9. Semi-protected areas affected only by high floods	Do.	725	192	17
10. Areas frequently flooded	... Do.	475	280	14
10. (a) High ground and jungle not ordinarily flooded.	Do.	278	124	8
11. Total length of embankments	... Miles	751 (564 Govt., 187 Private.)	178 (105 Govt., 73 Private.)	10 (77 Govt. 23 Private.)
12. Population in protected area	...	11,24,265	2,22,880	2,49,800
13. Ditto in semi-protected area	...	5,18,190	1,19,509	1,03,960
14. Ditto in the unprotected area	...	2,84,943	2,20,812	43,810
15. Cultivated area	... Square miles	1,560	437	460
16. Uncultivated area	... Do.	1,015	887	110

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APPENDIX VI-(A).

FREQUENCY OF FLOODS IN THE THREE MAIN RIVERS OF ORISSA.

4 feet below maximum high flood level is taken as danger level.

Mahanadi.—Maximum High Flood Level Naraj 92.00 on 4-7-1872.

Average maximum is 91.75.

∴ Danger level is 87.75

(P. C. Mahalanobis' Report—Table no. 174.)

Naraj Gauge, 1868—1929.

Probability of occurrence of assigned maximum gauge-heights in number of years per century.

Height exceeding.	1 day.	2 days.	3 days.	4 days.	5 days.
87.75	46.77	43.55	38.71	29.84	25.81
88.75	33.06	30.65	25.81	20.16	16.13
89.75	22.58	20.97	16.13	12.90	9.68
90.75	14.52	12.10	11.29	8.87	4.84
91.75	8.06	4.84	...	...	...
92.75	3.23	...	...	...	...

Brahmini.—Maximum High Flood Level Jenapur 70.60 on 17-8-1926.

Average maximum height is 70.00

∴ Danger Level is 66.00.

(P. C. Mahalanobis' Report—Table no. 265.)

Jenapur Gauge 1875—1929.

Probability of occurrence of assigned maximum gauge-heights in number of years per century.

Range in feet.	1 day.	2 days.	3 days.	4 days.	5 days.
65.8 —66.2	57.55	53.92	48.00	38.87	32.03
66.3 —66.7	49.08	46.13	41.17	32.62	27.32
66.8 —67.2	40.57	38.53	34.30	27.77	23.51
67.3 —67.7	32.55	30.66	28.09	23.79	20.70
67.8 —68.2	25.66	24.86	23.64	20.60	17.86
68.3 —68.7	20.19	19.74	19.66	17.17	15.70
68.8 —69.2	15.65	15.04	15.68	14.08	13.94
69.3 —69.7	12.26	12.93	13.80	12.09	12.42
69.8 —70.2	9.06	9.51	10.47	9.55	10.09
70.3 —70.7	6.60	6.96	7.77	7.80	...

APPENDIX VI-(A)—*concl'd.*

Baitarani.—Maximum High Flood Level Akhuapada 66·20.

Average maximum height is 65·75

∴ Danger level is 61·75.

(P. C. Mahalanobis' Report—Table no. 300 altered to 100 years.)
Akhuapada guage 1874—1929.

*Probability of occurrence of assigned maximum gauge-heights in
number of years per century.*

Height exceeding.	1 day.	2 days.	3 days.	4 days.	5 days.
61·75	49·90	32·15	26·80	16·08	10·91
62·25	35·75	28·58	19·64	14·28	7·15
62·75	28·58	21·42	16·08	8·94	5·35
63·25	25·00	17·88	14·28	5·85	...
63·75	25·00	14·28	5·85	1·79	...
64·25	17·85	8·94	1·79	...	...
64·75	10·71	7·15	...	...	...
65·25	7·15	1·79	...	...	...
65·75	7·15	...	...	...	...
66·25	9·57	...	...	...	...

APPENDIX VI-(B.)

Population in protected and exposed tracts.

Thana.	Protected areas.	Areas flooded in high floods only.	Areas frequently flooded.	Total.
MAHANADI DELTA.				
Cuttack	1,28,005	86,800	27,743	1,92,048
Salepur	2,17,649	25,200	28,600	2,66,449
Dharmasala	7,940	5,600	500	14,040
Jagatsingpur	2,40,797	56,000	9,700	3,06,497
Tirtol	1,77,191	15,500	800	1,93,491
Kendrapara	1,17,969	69,800	84,800	2,22,569
Patamundai	900	22,900	1,200	25,000
Puri	1,22,500	61,000	68,000	2,46,500
Gop	5,814	65,800	57,800	1,28,914
Pipli	1,05,800	1,55,890	11,500	2,72,890
Khurda ... ..	...	4,200	4,800	9,000
Total	1,124,265	5,18,190	2,84,943	18,77,398
BRAHMINI DELTA.				
Dharmasala	1,29,000	59,889	72,000	2,60,889
Jajpur ... ..	...	19,500	70,500	90,000
Aul	13,500	22,200	50,000	84,700
Patamundai	60,000	13,800	28,812	1,02,112
Kendrapara	21,880	4,120	...	25,500
Total	2,22,880	1,19,509	2,20,812	5,63,201
BAITARANI DELTA.				
Dharmasala	4,000	20,500	...	24,500
Jajpur	1,47,189	83,600	11,000	1,91,789
Aul	9,617	18,500	8,500	36,617
Chandbali ... ..	...	18,360	12,850	31,210
Dhamnagar	89,000	12,000	11,000	1,13,000
Total	2,49,806	1,03,960	43,850	3,97,116
Total for the three deltas	15,96,951	7,41,659	4,99,105	28,37,715

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