
THIRD INTERIM REPORT
OF THE
ORISSA FLOOD ADVISORY COMMITTEE
February 1942.

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ORISSA FLOOD ADVISORY COMMITTEE.

February 1942.

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* Printed in a separate volume.

Third Interim Report of the Orissa Flood Advisory Committee, February 1942.

SECTION I.

BRIEF RETROSPECT.

Since we last met in January 1940, when our Second Interim Report was submitted, Mr. S. K. Roy, B.A., B.E., Chief Engineer and Secretary to Government, Public Works Department, Orissa, has taken the place of Mr. A. Vipan, C.I.E., M. Inst. C. E., on this Committee on the latter's retirement in March 1940.

2. In our First Interim Report, dated January 1939, we clearly laid down a general policy to be followed in the matter of flood protection, and both in that and in the Second Interim Report, dated January 1940, we made various suggestions for collection of hydraulic and other data required for formulating schemes in accordance with that policy. We also made certain recommendations for improving the conditions of flood-affected tracts on the basis of the then available data and knowledge of local conditions obtained during inspections.

Mr. Shaw has, during the interval of two years since our last meeting, completed a contour survey of the flood-affected delta, collected much useful data, and has studied the conditions in the areas affected by the floods of 1940 and 1941 and has prepared for our information several notes, maps and plans. He has also inspected the deltas of the Godavari and Kistna rivers in the Madras Presidency, the conditions in which we believed to be more akin to those of the Orissa rivers than to those of the Bengal delta.

Reference is invited to his notes of inspection describing and comparing the conditions in the several deltas and the other notes mentioned above, which are appended to this report.

3. In our First Interim Report we stated:

“ the 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 (of that report) the quantity of silt which can be carried by a river increases roughly proportionately to the velocity 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 net-work 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."

Based on this, we laid down a policy, vide para. 9 of the same report, which should be adhered to. This is reprinted for ready reference :

" 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."

After a study of the notes and examination of the data so far collected, and also as a result of our further inspections during this month in Cuttack and Puri districts, we would emphasise that a cardinal feature of our policy is to confine the flow in each main river to a single channel by effective embankments, by restricting spills and closing undesirable channels. In other words we are of opinion :—

- (a) To improve a river, it is necessary (i) to improve the outfall conditions ; (ii) to control the distribution of water and sand entry at the heads of channels ; (iii) to restrict the number of channels.

- (b) Without double embankments, deltaic rivers break up and deteriorate. Double embanking in conjunction with the other measures recommended, retards or prevents such deterioration.
- (c) Double embankments necessitate the provision of high-level escapes. With the improvement of the river channels, the depth of spill through these escapes should be gradually reduced.
- (d) Control by double embankments and escapes should be combined with suitable drainage of the basins between rivers.

In giving effect to this policy it may be necessary in certain cases to carry out river training works, such as closing certain channels, developing others, constructing spurs to control the direction of flow, and protecting river banks.

4. There is one point to which we have made no reference in our previous reports, namely the effect of deforestation on floods. We understand that, in some of the Orissa States, deforestation is being practised on a somewhat extensive scale. Though opinions differ in regard to its effect on the maximum floods, there is no doubt that denudation of forests unless followed by reforestation or natural rehabilitation, will intensify the deterioration of rivers due to increase of debris entry. There would be no objection to the removal of dense tree-growth under the expert advice of the Forest Department, but indiscriminate cutting should be prohibited.

Conversion of forest land into agricultural land would, by increasing the run-off, bring in large quantities of silt in the early floods. There will also be a diminution in the cold weather flow. Such conversion should, therefore, be discouraged if it cannot altogether be prohibited.

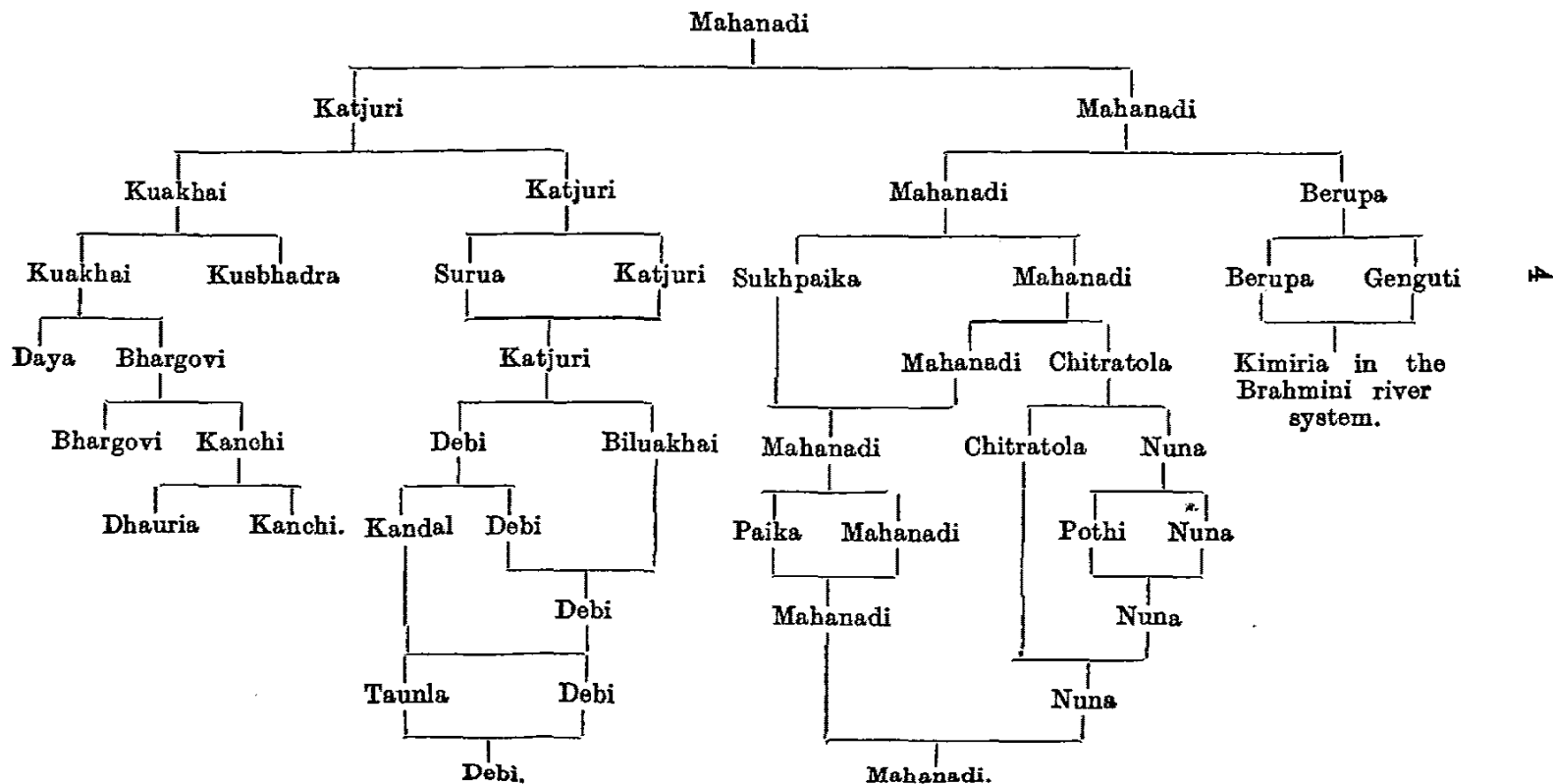
SECTION II.

SPECIFIC PROPOSALS FOR FLOOD PROTECTION.

5. We now proceed to make some specific recommendations in addition to, or in modification of, those already made in our previous reports, in accordance with the above principles. These proposals are all indicated in red in the index map in the separately bound book of maps to accompany this report.

MAHANADI SYSTEM.

6. This system includes the following rivers : Mahanadi, Katjuri-Surua-Debi, and Kuakhai, and their branches as shown in the schematic diagram below :—



7. *Mahanadi*.—In the case of the Mahanadi-Paika-Chitratola-Nuna islands the flood situation is not so acute as to necessitate any major protective operations. The existing embankments should be maintained or retired as may be necessary, and the development of low spills should be prevented. Existing high spills should be allowed to continue.

The Nuna and Paika rivers appear to be improving very gradually at the expense of the Mahanadi and Chitratola. It is not proposed to take any action at present to interfere with these respective developments.

To accelerate the improvement in the Nuna, it is desirable to restrict flow in the Pothi. The possibility of getting the river itself to achieve this objective should be investigated as the natural conditions appear to be favourable.

8. *Katjuri-Surua-Debi*.—In consonance with our principle we consider that the Biranasi spill and that over the Banki road should be stopped if this will not increase the readings of the Katjuri gauge at Bellevue by more than six inches. To obtain information regarding this and other points in doubt, we propose that the model experiment, as already recommended in the previous reports, be undertaken at Poona with a model of the Mahanadi and upper Katjuri. This experiment will give information concerning—

- (i) conditions affecting the distribution of sand entry at Naraj;
- (ii) the immediate effect of closing the spills at Biranasi and across the Banki road, on Bellevue gauge readings;
- (iii) the effect of improving the Surua to pass an increased discharge; and
- (iv) the probable effect of such changes on the position of the upper Katjuri channel.

Incidentally, this model would help to determine the waterway required for a bridge if constructed across the Mahanadi near the Fort at Cuttack, and the effect this bridge would have on sand distribution between the Mahanadi and Katjuri rivers.

9. With regard to the flood spill on the lower Debi right bank in the Kakatpur area, we have in our reports [First Interim Report, page 20, paragraph 51(iii) 2 and 3, and Second Interim Report, page 14, paragraph 5(c)] recommended investigating the desirability of an embankment from embankment 1B

at Lataharan north to Hasanpur and Madhab, and also closing temporarily the breaches in embankment 2B. With the exception of the temporary closure of the breaches in embankment 2B, we now confirm these previous suggestions and recommend these works, being done. The breaches in embankment 1B on the right bank of the Debi, lower down may be left open for the present.

In our Second Interim Report we recommended that Government should take over the Debi-Kandal private embankments as far as the Tel river mouth, and close the Manikunda breach. We now confirm this and further recommend the extension of this embankment down the right bank of the Kandal, closing the Taunla river head, and linking up with the existing embankment which extends to the Debi. From this point the existing embankment should be extended down the Debi right bank to the mouth of the Taunla.

10. *Kuakhai*.—In our second Interim Report we have made the following recommendations:—

- (i) Improving the conditions in the Dhanua basin by constructing a double-embanked channel from the Dhanua to the Dal Nadi which flows into the Sur Lake.
- (ii) Improving the section of the Sur Lake Sea Cut and constructing a temporary masonry sill at the road crossing.
- (iii) Preparing designs for a double-embanked channel with control sluices for diverting part of the Bhargovi river at Gobakund into the Sur Lake.
- (iv) Double-embanking the Kusbhadra river as far as the coastal sandhills at Alanda, strengthening and raising the existing embankments, and providing sluices for irrigation as required.

An estimate has since been sanctioned for the first proposal and the work is being taken up.

As regards the second, in the light of later data we consider it necessary to construct a masonry sill as a permanent measure at the level already proposed, except for a central width of 200 ft. which should be at R. L. 3'00 with regulating gates. The rest of the sill at R. L. 7'00 may be provided with falling shutters to store water in the lake up to R. L. 10'00. This arrangement will accelerate run-off from the Sur Lake during floods and afford further protection to the low lying

flooded area of the Dhanua basin. It will also improve the outfall from the Bhargovi through the Kanchi. For this purpose it is also desirable to improve the entry conditions at the offtake of the Kanchi by a diversion cut for which an estimate should be prepared.

As regards the third proposal, it is roughly estimated that it will cost some Rs. 3 lakhs and as the immediate benefits to be derived will be much less than from the Kusbhadra scheme [(iv) above], we consider that this scheme should be given preference.

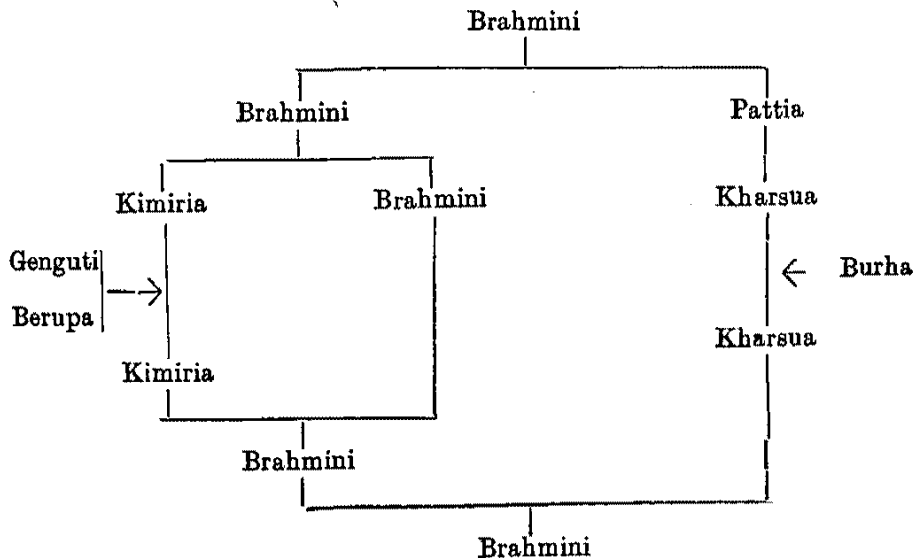
The Kusbhadra scheme is estimated to cost about Rs. 5 lakhs and will afford flood relief to a large extent on both banks of the Kusbhadra and in the Kadua area and low coastal lands.

The Tirimul breach on the Daya right bank should be closed or restricted and an embankment provided on this bank from Tirimul down to near the Monaguni junction, the left embankment being strengthened as required.

After the results of the model experiment recommended in para. 8, section II, of this report are known, the measures necessary for improving the Kuakhai from its head to the Bhargovi-Daya bifurcation will be considered.

BRAHMINI SYSTEM.

11. This includes the Pattia-Kharsua and the Kimiria as shown in the schematic diagram below, also the entry of the Berupa river from the Mahanadi system, and the Burha river from the Baitarani :—



The Brahmini river has long been observed to be deteriorating while the Pattia-Kharsua has been developing, and this development would have been very much more rapid but for the construction of the Pattia weir in the year 1890. According to the policy recommended by us, any scheme for flood protection should aim at the acceleration of the natural development of the more favoured channel, in this case the Kharsua. But the Brahmini in recent years has been found to be slowly reviving from the anicut at Jenapur as a much smaller channel than its original size. The Berupa and the Genguti which branch off from the Mahanadi, enter the Brahmini system and have helped to keep it as a good going river in its middle reach. In view of these natural conditions it seems advisable to watch developments before taking up any comprehensive scheme for flood protection; but certain works intended to give relief to the people in some of the badly affected tracts are proposed.

12. *Brahmini*.—The crest of the Jabra escape should be raised gradually as conditions in the river improve, and the existing Government embankments should be maintained.

13. *Pattia-Kharsua*.—This river should be double-embanked from below the weir to the Kani Nadi head with provision for high-level escapes as may be necessary.

The Burha river, which is a branch of the Baitarani joining the Kharsua about 19 miles below the Pattia weir, should be embanked on its right bank from the Burha anicut to near its junction with the Kharsua. The Jamuna and Similia channels may be closed.

BAITARANI SYSTEM.

14. *Burha*.—This includes the Burha river which flows into the Kharsua and has been dealt with under that head. The Burha river is continuing to improve gradually at the expense of the Baitarani. We do not propose to interfere with this action at present.

15. *Baitarani*.—The right or western loop of the Baitarani below the anicut has deteriorated considerably and this process may be accelerated by closing the head gradually.

The upper head of the Genguti should be closed, the existing Baitarani left embankments being extended from Kazisahi as required. It is also desirable to have the Genguti main offtake closed by the natural action of the Baitarani river itself, and investigation to this end should be taken up.

The Kochila Nadi which is a northern loop of the mid-Baitarani has been developing for many years at the expense of the main river. We do not recommend any action to be taken here at present but the situation should be watched.

SECTION III.

PROGRAMME OF WORKS.

16. Appendix II of our Second Interim Report is a list of recommended works, and the action taken thereon is outlined in Appendix V of this report. It is hoped that the works already in progress or sanctioned and awaiting funds will be pushed forward. In accordance with the recommendations now made we give below an extended programme of works.

List of Works.

1. Model Experiment of Mahanadi delta head (para. 8).
2. Sill and regulator in Sur Lake Sea Cut (para. 1).
3. Diversion of the Kanchi head (para. 10).
4. Reconstruction of Debi-Kandal right embankment as far as the Tel drainage and closing Manikunda ghai (para. 9).
5. Double marginal embankments on Pattia-Kharsua as far as the Kani Nadi head with high-level escapes where necessary (para. 13).
6. Constricting an embankment on the right bank of the Burha river from below the anicut to near the Kharsua junction including closing Jamuna and Similia channel heads (para. 13).
7. Constructing an embankment on the right side of the Debi river from Madhab to Hasanpur and Lataharan connecting up with embankment 1B (para 9).
8. Double embanking the Kusbhadra river to the coastal sandhills at Alanda with any necessary high-level escapes and drainage sluices and closing the eastern loop of the river (para. 10).
9. Closing the Tirimul ghais on the lower Daya right bank and constructing an embankment from there to near the Monaguni junction (para. 10).
10. Constructing an embankment along the right bank of the Kandal from below the Tel drainage to the Taunla head, closing the Taunla head and extending the existing Kandal-Debi right embankment downstream to the Taunla outfall (para. 9).

11. Raising the crest of Jabra flood escape on the Brahmini gradually (para. 12).

12. Constructing an embankment from Kazisahi on the Baitarani left bank downstream to beyond the upper Genguti river head including closing that head (para. 15).

13. Closing gradually the head of the old Baitarani river loop below the anicut (para. 15).

14. Investigating measures to accelerate the natural deterioration of the Genguti river head on the Baitarani river (para. 15).

N. B.—In the case of some of the above items comprising a more or less complete scheme for the river, it should be understood that the order of works should be first to close the breaches or spills from downstream upwards, then to construct the outer boundary embankments from upstream downwards, then to construct the remaining embankments as conditions may indicate.

It should also be understood that it is not desirable to restrict the department in the actual order of urgency of certain works, and general schemes given above may be subdivided and the order altered as long as the above principles are followed.

The order of precedence will depend to a large extent on the amount of funds that Government may allot from year to year.

SECTION IV.

FURTHER SURVEYS AND INVESTIGATIONS.

17. Much useful data has been collected during the last three years. In the preceding sections of this report suggestions have been made for further investigations required for formulating schemes. Of these we attach great importance to the model experiment referred to in para. 8, section II, of this report. We request that immediate steps be taken to obtain the necessary funds for carrying out this experiment, as on the results thereof final recommendations regarding the improvement of conditions at the head of the Katjuri will largely depend.

We also wish to emphasise the necessity, as already recommended in our Interim Report of 1939, of detailed surveys being made of the rivers at places where scours are developing such as along the Katjuri below Naraj. A yearly record of how these scours are developing should be maintained. With his intimate knowledge of the delta, Mr. Shaw will be able to select suitable reaches for each of the delta rivers.

Discharge and slope observations should be continued and correlation curves prepared.

Observations for determining silt and sand charges in rivers have been carried out and they have given useful results,

particularly in the case of the Bhargovi. As this is a very important work it should be continued and extended until complete data is available for the main rivers.

Investigations should be carried out as to the possibility of devising means to eject a portion of the sand charge from the Mahanadi river above Naraj.

The automatic gauge recorders at present in stock should be utilised for observing the effect of lowering the bed of the Sur Lake Sea Cut on the flood levels in the Sur Lake, and the Kanchi and Bhargovi rivers.

A standard Siltometer (Dr. Puri's) costing about Rs. 300 should be obtained and a certain number of samples analysed and graphs prepared to determine the distribution of grades of sand. These graphs will be required to give a further insight into conditions, especially where we take measures to encourage the deterioration of an undesirable channel.

18. As all the above investigations are of a specialised nature requiring trained personnel, we consider that continuity is essential. This work should, therefore, be entrusted to a single division and not split up among several divisions. The Flood and Drainage Division now in charge of this work, should be continued for at least two years.

SECTION V.

CONCLUSION.

19. The programme now put forward will, we hope, enable Government to decide the allotments to be made in the Provincial Budgets during the next three to five years, and to undertake the works in order of urgency. It should be remembered that once a work is sanctioned it ought to be carried out with reasonable expedition and completed within a period not exceeding three years. It is only then that the benefits anticipated will be realised and the people gain confidence.

20. The flood problem in Orissa should be a matter of continuous investigation and comparative study. Based on this, remedial measures may have to be modified in detail, but the broad policy should always be kept in view.

M. G. RANGAIYA.

C. C. INGLIS.

S. K. ROY.

The 5th February 1942.

APPENDIX I.**Diary of tours.**

- 22-1-1942 }
to } Meeting in Cuttack. Examination of data and discussion.
24-1 1942 }
- 25-1-1942.. Cuttack to Dalaighai, Jagatsingpur, Alipingal, Mun lilo, Taunla river head and back. Inspected part of the Katjuri-Debi river system.
- 26-1-1942.. Cuttack to Paradip and back. Inspected Mahanadi river from right bank at various places, studying meanders and important alterations.
- 27-1-1942.. Halt at Cuttack. Examination of data and discussion.
- 28-1-1942.. Ditto ditto.
- 29-1-1942.. Cuttack to Marsaghai and back, studying Mahanadi and Nuna rivers. Inspected Mahanadi left bank at Satbatia, Chitratola head at permeable spurs, Kendupatna, Chitratola-Nuna bifurcation, Danpur scour and Pothi head, Pothi outfall and alterations at Marsaghai.
- 30-1-1942.. Cuttack to Puri. Inspected Barang river, Daya-Bhargovi bifurcation, Kusbhadra head, Jogisahi escape, Kanchi head and Dhauria head. Puri to Sur Lake Sea Cut and back, examining lake bed and cut.
- 31-1-1942.. Halt at Puri. Discussion.
- 1-2-1942.. Puri to Cuttack.
- 2-2-1942.. Cuttack. Preparation of report.
- 3-2-1942.. Ditto.
- 4-2-1942.. Cuttack. Report finished.
- 5-2-1942.. Report finally approved.

APPENDIX II.

Catchments, rainstorms and floods in Orissa rivers.

INTRODUCTION.

For the proper study of the floods and rivers in the Orissa delta it is necessary to study the cause, source, occurrence, size and duration of the floods which arrive at the delta from the river catchments.

There are three main rivers which cause floods in the Orissa delta, the Mahanadi, the Brahmini and the Baitarani. The course of these rivers, the formation of their catchments, and the distribution of rainfall from June to September may be seen in the map in the booklet of maps to accompany this report. This map has been prepared by Professor P. C. Mahalanobis, the eminent statistician. The following table gives details of the three rivers :—

		Mahanadi.	Brahmini.	Baitarani.
Total length of river ...	Miles	553	438	315
Length from source to head of delta.	Miles	466	345	153
Catchment area above delta.	Sq. Mls.	51,000	14,000	4,000
Total average rainfall in catchment from July to September—				
(a) Maximum ...	Inches	52·6	54·8	49·7
(b) Minimum ...	Inches	26·7	19·8	15·6
(c) Average ...	Inches	34·0	36·9	32·1
Discharge at head of delta—				
(a) Maximum ...	Cusecs	1,571,000	643,290	409,000 in 1940, 700,000 or more in 1927.
(b) Minimum ...	Cusecs	200	130	74
Discharge per sq. mile of catchment.	Inches	30	46	102 and 175
Total area of delta ...	Sq. Mls.	2,940	854	659

A fully detailed account and analysis of rainfall and flood behaviour in the river catchments is given by Professor P. C. Mahalanobis in his large report on this subject "Rainstorms and River Floods in Orissa". As a condensation of this information with some additional observations and deductions by myself the following notes are submitted.

RAINFALL.

About 85 per cent of the total annual rainfall in the river catchments falls in the monsoon months from June to September inclusive, so rainfall and floods are definitely seasonal. Rainfall and consequently floods, on the average, reach a peak in the last week of July and first week of August, but major floods have occurred in all rivers at times from almost the 1st of June to the 10th of October.

The red line in the map shows the mean path of the centre of storms affecting the catchments of the Orissa rivers, and is seen to cross the Orissa coast about 25 miles south of Balasore. The general travel of the centre of the storms is west-north-west, and the average rate of travel is 200 miles per day. The greatest intensity of rainfall is not necessarily along the centre of the path of travel but is affected largely by physical features. The general sequence of events is that during the monsoon season depressions form in the northern part of the Bay of Bengal. These often move in an uncertain manner off the coast until they take a definite trend and pass westwards over the country. Although the depressions often hang about lower Bengal and sometimes in Chotanagpur, they seldom linger in crossing the Baitarani, Brahmini and Mahanadi catchments. Maximum floods in the Baitarani are due to occasional great intensity of rainfall as the storm passes across the catchment. In the Brahmini and the Mahanadi, maximum floods are generally caused by depressions passing across the catchments then circling round north of the catchment areas, passing east to Bengal and again passing west over the north catchments within a period of five days or so. This superimposes a second flood on the first flood before the first flood has quite gone off, and while the river is still running high and the ground wet.

No cycle of rainfall has been traced for the Mahanadi river system, probably because it covers such a large area, but in the case of the Brahmini and Baitarani, Professor P. C. Mahalanobis has found that the Brahmini catchment from 1894 to 1904 had an increasing amount of rain, from 1904 to 1911 steady, from 1911 to 1918 decreasing and from 1918 to 1928 an increasing amount. The curves of total rainfall are roughly parabolic with a 24-year's interval between turning points. Similarly he found that the Baitarani catchment area from 1891 to 1899 had decreasing rainfall, nearly steady from 1899 to 1916 and increasing from 1917 to 1927. Only the latter period, that of the 1915 to 1929 rise, corresponds with the Brahmini cycle. From 1929 up to 1940 there seems to be no definite cycle of rainfall. Although the river levels run higher in years of greater average rainfall it is found that the occurrence of the bigger floods does not fit the rainfall cycle well, and this emphasises the generally known fact that it is the intensity of a particular storm which determines maximum floods much more than does the average seasonal rainfall. The state of the river-bed and effect on the banks and unprotected country will however be different in the period of years when the average river stage is higher and this is to be taken into account when comparing the state of the river in different periods.

THE MAHANADI.

Catchment, rainfall and run off.—The Mahanadi catchment (51,000 sq. miles) is roughly circular with a diameter of 250 miles and with an exit passage about 100 miles long and 35 miles wide leading to the delta at Cuttack. The catchment is a fairly regular basin surrounded by high lands and the river escapes from this basin through a passage in the hills to the delta. The isohyetal lines, or lines of equal rainfall, from June to September, show that the heaviest rainfall (60 inches) is confined to a small area between Sambalpur and Sonepur. Thereafter the next heaviest rain is in the north-east part of the catchment. The central and south part of the catchment receives about 45 to 50 inches rain and the rainfall decreases to the east and the south. Rainfall in the west of the catchment generally occurs about 40 hours after the rain at Cuttack.

The rainfall causing heavy floods usually occurs in well marked patches of very heavy rain resulting in an average rainfall over the whole catchment of considerably over one inch per day for about three consecutive days, and moderately heavy rain of over three quarters of an inch per day for about five consecutive days, with maximum flood at the head of the delta at Naraj one day later. General average rainfall of one inch per day for three days causes a short flood with maximum flood at Naraj on the fifth day. The flood level at Naraj generally rises regularly for three days, slows up on the fourth day, then falls slowly.

The average rate of run-off of the rainfall to the main river and down the main river is four miles per hour except on part I of the catchment above Naraj when the river slopes are much flatter.

The average rate of travel of the flood from Sambalpur to Cuttack is—

116 miles at $5\frac{1}{2}$ miles per hour	=	21 hours.
20 miles at 6	„	= 3 „
50 miles at 3	„	= 17 „
Total ..		<u>41 hours.</u>

The alteration in rate of travel is due to the general slope of the country, the narrow gorge and then the frequent wide flat expanses above Naraj. The actual time of travel of the flood peak from Sambalpur to Cuttack can vary from 36 to 53 hours depending on the size of the flood, the intervening rainfall and the previous state of the river.

An important factor in estimating floods at Cuttack from Sambalpur is the state of the Tel tributary which has a large catchment and enters the Mahanadi 46 miles downstream of Sambalpur at Sonepur. This river is capable of producing a considerable flood at Cuttack before the flood from the Mahanadi above Sambalpur arrives at the junction of the Tel and Mahanadi rivers.

A system of forecasting has been prepared from a practical study of rainfall from Sambalpur westwards, which forecasts the rise of the river at Sambalpur and by correlation of the river warning gauges at Sambalpur and Sonepur with Cuttack. Results are very satisfactory.

From Professor Mahalanobis' figures it is determined that the average percentage run-off for the Mahanadi catchment, i.e., river flood volume compared with volume of rainfall in the catchment, decreases within limits as the amount of rainfall in the same period increases. The increase or decrease of percentage run-off with the extension of the period for the same amount of rainfall is doubtful although Mahalanobis considers that the percentage increases with the period. Some average results were—

For 3 days' rain	1,390 kilocusecs	69%	run-off.
	3,086	44%	„
For 4 days' rain	1,275	68%	„
For 6 days' rain	1,134	76%	„
	2,190	47%	„
For 10 days' rain	862	73%	„
	1,665	51%	„

Height and duration of floods.—As the size and state of a river channel in alluvium depends on the volume and frequency of water supplied from above, it is necessary to consider this important question. A graph deduced from tables 142-5 of Mahalanobis' report is given in the book of maps to accompany this Orissa Flood Advisory Committee report and shows the average number of times certain gauge heights at Naraj were equalled or exceeded per year in 62 years (1861—1929) for each month, and for the combined flood season July to September. A line is drawn in the graph showing the state of Naraj gauge (87·5) when the rivers in mid delta are about bank-full.

A graph is also attached deduced from Mahalanobis' table 154, 156 and 164 showing the average frequency per year in 62 years of average heights exceeded at Naraj for 3, 5, 7 and 10 consecutive days in the flood season.

These graphs give a good idea of the stages of flood which control the formation of the Mahanadi river system. Another point is that the embankments in Orissa, if exposed to a high flood for a prolonged period, percolate in many places and there is a chance of earthslips and breaches. A flood height of 25 at Bellevue gauge at Cuttack on the Katjuri river or 89 at Naraj for more than three days may be taken as indicating percolation danger. This line is drawn on the graph. From the height and frequency of occurrence of maximum floods we can also fix the safe economical minimum height to which embankments should be raised. It was observed that 91·75 at Naraj was exceeded only five times in 62 years, the common maximum of these five floods being about 92·00 while the actual recorded maximum of 93·4 previous to this is doubtful. It is therefore worthwhile to design embankments to withstand a flood corresponding to 92·00 at Naraj but no higher.

THE BRAHMINI.

Catchment and rainfall.—The Brahmini catchment (14,000 sq. miles) is of the long shaped sausage type. It lies north and south, total length about 246 miles and average width 58 miles, with a bottle neck constriction midway. Mahalanobis has divided the catchment into two parts—the south part, part I below the bottle neck about 5,600 sq. miles

and the second or north part, part II 8,400 sq. miles. The catchment area is a long shallow valley sloping seawards fairly regularly from the high hills in the north.

The isohyetal lines in the map show the average monsoon rainfall indicating heavier rain in the northern part of the catchment. The central path of the storms passes just north of part I. The maximum intensity of average rainfall for two consecutive days in the 38 years from 1891—1928 is $5\frac{1}{2}$ to 6 inches for one day and 4.1 inches for three consecutive days for part I, and 5.5 inches for one day and 4.3 to 5.8 inches for three consecutive days for part II. The probability of heavier rainfall occurring is much greater in part II on the north.

Such an elongated catchment with rainfall passing across it from one side indicates almost simultaneous rainfall and flooding throughout the catchment, but the catchment is so long that it is not generally covered by one storm moving transversely. The length of the catchment also means that the floods from rainfall in the south have some chance to pass partly away before the full effect of the northern rainfall and floods arrives. The result is a more prolonged type of flooding below. Mahalanobis has calculated that for 1 inch rise in the average rainfall in part I the rise of the river at Jenapur would be 5.42 feet whereas the same addition in part II would only cause a rise of 3.31 feet in spite of that catchment area being 50 per cent larger.

The observed apparent cycle of rainfall in the case of the Brahmini has already been remarked upon. The cycle of rainfall is not so apparent since 1929. The average rainfall increases gradually with the season, reaching a peak in the last week of July and first week of August, then decreasing slowly in August and more quickly in September.

Size and duration and frequency of floods.—Following the trend of rainfall seasonal intensity the average height of the river gauge at Jenapur rises from 57 in the beginning of July to 60 in mid August and slowly decreases in the end of September to about 59.

A graph is given in the book of maps attached to this Orissa Flood Advisory Committee report deduced from Mahalanobis' table 249 showing the average frequency per year of gauge readings at Jenapur at the head of the delta from 1875 to 1929 for the months of July, August and September separately and combined.

The Jenapur gauge reading at which the rivers Brahmini and Pattia begin to overflow their natural banks in mid delta is about 69.0 and this is shown by a line in the graphs.

Another graph is given in the book of maps attached to this Orissa Flood Advisory Committee report deduced from Mahalanobis' tables 262 and 274 showing the average frequency per year of river levels for 3, 5, 7 and 10 consecutive days during the period 1875 to 1929. This gives an idea of the size of controlling floods.

Mahalanobis has shown that the variation or cycles of flood height follow the rainfall very closely so that there is no indication of flood levels at Jenapur rising beyond those caused by the same rainfall in the last century, i.e., there is no indication of a general rise in bed or ground levels at the head of the delta so deltaic action there has apparently ceased.

THE BAITARANI.

Catchment and rainfall.—The Baitarani catchment (4,000 sq. miles) is roughly circular, about 61 miles in diameter, with a neck about 35 miles in width and length extending to the head of the delta. There are high ranges of hills on each side of the catchment and a central lower range which causes part of the west catchment rainfall to run off to the north before outflanking the high ground and joining the main central valley. This causes some delay in what would otherwise be one of the worst types of catchments for quick flooding.

The average central path of storms affecting the catchment passes right through the centre of the area and the whole catchment can be covered by one rainstorm. Although most of the catchment is under the 45-inch isohyetal line the sudden intensity of rainfall can be very great and this is what causes the extraordinary floods in this river. The facts that the catchment is fairly close to the sea and has high boundaries are doubtless leading factors in causing this great intensity of rainfall.

As in the other Orissa delta river catchments which are under the same monsoon and general path of rainstorms, the rainfall increases from June to a maximum at the end of July and beginning of August, and declines slowly to the end of September. The maximum recorded local rainfall was in 1927 at Champua in the north of the catchment when on 29th July, 22·92 inches of rain fell in 13 hours. The average rainfall over the catchment on 30th July 1927 was 6·58 inches and for the previous day 6·14 inches. The consequent flood was so overwhelming that it reached a height in the channel of 50 feet at Anandpur in the catchment exit where the cold weather depth is 3 feet. Again in 1940 and 1941 extraordinary high floods took place due to great rainfall intensity. By careful observations at several places in the valley above Anandpur and elsewhere it was calculated that the 1940 flood was about 409,000 cusecs at its peak flow. The 1927 flood was 10 feet higher than this and is roughly calculated as being about 700,000 cusecs or more at peak discharge. When such enormous floods passed out from the river valley they spread over the delta plain for about 7 miles to the west and 10 to 12 miles to the east, overtopping and breaching all cross drainage works and passing off to the Bay of Bengal like a vast sea.

Size and duration of floods.—A graph is given in the book of maps accompanying the Orissa Flood Advisory Committee report deduced from Mahalanobis' table 287, showing the average frequency per year of gauge readings for Akhuapada for July, August and September separately and combined from 1874 to 1929.

The gauge reading at Akhuapada corresponding to bank-full conditions in the delta is R. L. 59·0 above the anicut and 56·5 below corresponding to gauge readings of 60 and 57·5.

A graph deduced from Mahalanobis' table No. 300 is given in the book of maps which gives the average yearly frequency of maximum gauge height from 1874 to 1929 for 2, 4 and 5 consecutive days.

It is noted by Mahalanobis that between 1874 and 1884 there was a definite rise of about 6" per year in the mean level of the Baitarani at Akhuapada. This must be largely due to construction of the anicuts and shutter control.

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APPENDIX III.

Orissa delta and delta river growth and alterations.

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INTRODUCTION.

To determine the possible future changes in the Orissa delta and its rivers and the degree of control which may be exercised in future, it is advisable to study the past history of the delta and its rivers.

The most important point in studying a river system for control is to find out whether that river system or combination thereof appears to have built up its flood plain and slopes sufficiently and to be comparatively stable, in this case even as a delta formation. This will require a study of the general shape and growth of the delta, any known alterations in river courses or capacity, alteration in tidal limits, and any evidence as to general or particular rise of river beds and ground levels.

THE DELTA.

General Features.—The Mahanadi delta is the main delta and overlaps the adjoining Brahmini river delta and the Baitarani overlaps the Brahmini area. The Salindi river, a considerable hill stream, also contributes to the Baitarani delta area on the north-east. The approximate sphere of the separate deltas is as shown in the map in the book of maps. The map also shows the position of the coastal hills and the contours indicate the ground features.

There is little to say geologically about the delta. As far as borings have gone, the delta lands are pure alluvium, sand and clay with no fossils found. In Balasore, to the north-east of the delta, borings have shown grey sand with numerous small shell fish and fish-fossils. The hinterland is for the most part very old rocks consisting of Archæan crystalline rocks in the east changing gradually to hornblende rocks and quartz schist to the south-west. There are big stretches of laterite soil in the higher lands above the delta plain. A noticeable feature is the projection of the hills towards the coast between the Mahanadi and Brahmini rivers with rock outcrops occurring for some distance into the delta. The other direct interference with the delta is the Khurda hills bordering the delta from its head to the Chilka Lake.

Geologists suppose that there has been a certain amount of general raising of the land from the hills to the sea but not noticeably within historic times. According to the drift theory of continents and oceans this might be expected on the east coast of India. There are many higher sandy ridges near the coast which are either old raised beaches or old storm debris lines.

The general coastline of the delta is of typical delta shape projecting into the sea in a sector of a circle. On the west side is the big depression known as the Chilka Lake which is obviously a part of land too far from the direct flow of the big rivers to have been built up at the same rate as the rest of the delta. It has been shut off from the sea by the raising of the land and the extending sand drift along the coast, and is very gradually silting up at its east end by flood water from the Daya and Bhargovi rivers and the sediment driven eastwards by the prevailing high

winds on the lake. A similar depressed area occurs between the Godavari and Kistna deltas called the Colair Lake although this is cut off much further from the sea.

An important factor affecting the delta growth is the strong littoral current travelling north up the Bay of Bengal which has limited the southern growth of the delta by sweeping the silt of the river waters up the Bay of Bengal. Beyond the Dhamra mouth however the littoral current is deflected and lost, and consequently the greater part of the delta river silt is swept north into the big bay called the Balasore Roads which are in consequence silting up. The map referred to previously shows the recorded fathom lines off the coast.

Regarding the growth of the delta into the sea, there is lack of good evidence as none of the old maps available are at all accurate. It seems fairly certain however that there has been no noticeable extension of the delta on the Puri side for a very long time. The extension of the Daya-Bhargovi deltas into the Chilka Lake is local and obvious but apparently very slow. Also there are no big rivers entering the sea in the Puri coast until the Debi is reached. The Debi mouth shows an extension of about three-quarters of a mile in the last century. The Mahanadi mouths have extended gradually and the occurrence of cyclonic storms with large tidal waves which occurred four times last century may have assisted in raising the land. It will appear from whatever evidence can be produced, that the Mahanadi mouth has extended about $2\frac{1}{2}$ miles since 1838 although the mainland has only extended about 1 mile, and the backwater bay (Hukitola Bay) on the north has been silting up at the rate of about 2 inches per year. The sea has recently broken through the neck of the spur of land protecting this bay, so if this opening extends it is possible that the deposits in Hukitola Bay may decrease as they are swept up the coast. South of the Mayapura and Dhamra river mouths the coast line, which projects to form a sort of spur, has for the last 70 years been eroding gradually. New land (the Wheeler Islands) has formed off the coast between the Mayapura and Dhamra mouths and it is evident that from the Mayapura northwards, the coastline is extending seawards and must have been doing so for a considerable period. A peculiar feature of the land north of the Dhamra is the very marked long high ridges of land occurring at intervals parallel to the sea coast. These are apparently raised beaches or more likely sudden deposits caused by tidal waves when the coastline was further back. These raised sandy ridges are drawn on the map and definitely show the gradual extension of the Brahmini-Baitarani delta in the shelter of the older and higher Mahanadi delta. The former delta must also have been created to a great extent by the Mahanadi silt being driven up the coast into the back bay just as the Mahanadi and Dhamra silt is at present carried north to the Balasore Bay.

The map shows all the higher ridges of land in the combined deltas as evinced by the contour levels taken and by the village sites which are taken along the higher ground. There are many clear indications of old delta channels or rivers which have served their time and passed away, as is customary in deltaic tracts. Some of these old channels were closed at the head only in the last century but many of them are now indicated only by higher ridges of land where deposits took place by the banks, or by very small deteriorated channels running along higher ridges.

River Entrance to Delta.—As previously observed, the delta is bounded on the south by the high lands of Khurda ; then comes the Eastern Ghats as the background through which the delta rivers find their way, and on the north-east are the Nilgiri hills and the narrow coastal plain into Bengal.

The Mahanadi river from a circular catchment of 51,000 square miles brings its maximum flood of 1,571,000 cusecs through the hills and starts its deltaic branching as soon as it is clear of the hills at Naraj. The fan-shaped distribution of rivers is typical of a free delta. The last 20 miles of the main river appears to be diverted northwards up the bay about 12 miles from its straight course. This is doubtless due to the strong littoral current, which increased in strength as the delta projected itself into the bay.

The Brahmini river with its long-shaped catchment of 14,000 square miles brings its 643,000 cusecs maximum flood through a much shorter series of hills and also branches into deltaic formation as soon as it is clear of the hills. Owing to confining high ground and hills on its west side it cannot spread in that direction and so the main channels continue more or less straight until they run into the fringe of the Mahanadi delta. On the east side the other main channel the Kharsua, runs almost parallel to the west channels, being apparently restricted to some extent by the influx of the Baitarani rivers. The Brahmini deltaic rivers in their lower half are most obviously all diverted from their straight course to a much greater degree up the coast than the Mahanadi. The divergence in this case occurs from about 25 miles inland and the mouths are diverted about 25 miles up the coast. This seems due to the strong littoral current and also to the pushing out encroaching effect of the Mahanadi delta.

The Baitarani river with its circular catchment of 4,000 square miles and extraordinary maximum floods varying from 4 to 7 lakhs cusecs, flows through confining hills for most of its course. When free of the hills it does not spread out in deltaic formation as soon as it enters the coastal plain but continues as one channel for more than one-third of its length to the sea before it bifurcates and gives off the Burha river branch to the west. This is partly explained by the fact that the general land slope and consequently river slope is steep and the land to the west is high.

The Salindi river, a considerable hill stream, while not having a delta of its own, seems to be taking a small part in the Baitarani delta and by division and alteration of its course shows delta river formations.

SOILS.

The nature of the soil of the delta is interesting as giving some indication of the formation of the delta.

The Mahanadi Delta.—In the Mahanadi delta bordering the Chilka Lake on the east, the ground levels are low and as far as the 10-foot contour towards the north-east the soil is black clay. Towards the south-east and round the Jagannath road and Bhargovi river the soil is a sandy loam. There also is the 2 to 3 mile wide strip of sandhills along the coast.

In the Dhanua Basin area between the Bhargovi and Kusbhadra rivers the soil is sandy near the rivers and a light clay in the centre of the doab.

In the Kusbhadra-Debi doab there is low land with black clay in the Kadua area but high sandy land all along the course of the Prachi. This shades off quickly on the east to black clay soil which continues to the Debi and beyond, but along the banks of the Debi and smaller channels the upper soil is again more sandy. Roughly speaking from the head of the Kendal river north we find light clay or sandy soils and to the south the soil merges into black clay with the usual silty covering near river banks.

The upper layer of sandy loam is about 15 to 20 feet deep on the banks of the Surua river, about 6 to 8 feet deep half way down the Debi, then diminishes irregularly to the coast where there is little.

In the upper Daya-Bhargovi and in the Kuakhai areas the soil is sandy and also all round Cuttack town.

Between the Debi and the Mahanadi the soil varies. In the lower half of the doab the soil is black clay, especially near the Debi, and in the upper part of the doab the soil is lighter and sandy in places. Irregular sand deposits occur within a few miles of the coast.

Bordering the Mahanadi for as far as the Nuna river confluence, the soil throughout is sandy. The Mahanadi island system with the Chitratola, Nuna, Paika and Sukhpaika rivers is all sandy soil bordering the rivers with some clay in the interior. In the lower parts of the Nuna and Paika islands below the 10-foot contour line the soil becomes clayey. Clay is not experienced in the Mahanadi bank to any extent until half way down the delta and is then at a low level. In the upper Chitratola banks there is about 12 feet of sandy loam before clay is found. In the Chitratola after the Nuna bifurcation, the depth of sandy soil in the banks is about 15 feet. In the Nuna river the sandy loam overburden is about 12 feet.

North of the Chitratola-Nuna river the land, which is sandy at the head of the delta, becomes less so towards the east and as the distance from the river increases.

In the Kendrapara area and to the east the ground is low and the soil is clay.

The Berupa and Genguti areas have loamy soils for the most part with light clay a mile from the rivers.

The Brahmini Delta.—At the delta head the soil is a sandy loam and this also is the case with the Kimiria-Brahmini island.

From half way down the delta where the lower lands commence, about the 15 foot contour line, the soil in the middle of the doab has become clayey and remains so except near the river banks, where there are the usual sandy deposits.

In the Brahmini river banks as far down as Damerpur there is still a considerable depth of sandy loam overburden on the clay bed, varying from 6 to 10 feet; beyond that the banks become lower and are clay.

The Kharsua river banks are much the same as the Brahmini but the clay bed is slightly higher.

East of the Kharsua the land rapidly becomes clayey, from about the 25 foot contour line and continues so to the Baitarani.

The Baitarani Delta.—The banks of the Baitarani above the anicuts are shallow and sandy but the lands behind are black clay especially towards the east.

The above feature of the Baitarani continues until it takes its bend to the south near the 10 foot contour. From here downwards and to the east everything is black clay.

The Salindi Area.—The lands of the upper Salindi are sandy loam and light clay but from near the 20 foot contour downwards the soil is black clay.

TIDAL LIMITS.

A good indication of the altering state of a river is the study of any alterations in the length to which the tide is active up the river course compared with former times. This is specially the case in the Orissa rivers where the littoral drift partially closes up the river mouths and the strength of the river is pitted against this current. If a river is in a deteriorating state it will not be carrying the same average volume of water in the monsoon and cold weather and consequently will not be able to maintain so good a mouth. Tidal effect will then be partially strangled with a gradual reduction in the scouring power of the tidal reaches and a reduction in the tidal limits from the sea. On the contrary an improvement of tidal activity and limits in the river would indicate an improvement in the river.

A point to remember also is that the larger the rise and fall of the tide on the coast the greater will be the scouring effect of the tide in the river estuary and channel. Thus near Puri the maximum tidal range is about 5·7 feet, at the Mahanadi mouth 8·4 feet and at the Dhamra mouth 11·0 feet.

The shape of the river estuary and tidal channel also affects its efficiency. The most efficient shape is a long trumpet shape as with this shape the tidal energy is piled up to give a greater volume of moving water than with other shapes where dispersal of energy takes place.

Chilka Lake.—There is no indication of any noticeable difference in the tidal range in the Chilka Lake. The fact that the sea mouth seems to keep open better on the average than in last century is an indication that there is no deterioration as the occurrence of floods is about the same. The tidal effect on the north shores of the lake is only a few inches and at the Bhargovi and Daya mouth is negligible.

During the hot weather when a steady strong breeze blows from the south-west the waters of the lake are piled up in the north-east corner to the extent of over 2 feet and flow up the channels of the Bhargovi and Daya rivers. The effect varies with the wind but is not connected with the sea-tides.

Kushhadra River.—Evidence as to the previous tidal limit is not to hand but it appears that there is no deterioration and in the Dhanua river

there is an improvement. The Kusbhadra mouth gives no more trouble now than formerly and is if anything better. The tidal limit is 16 miles from the mouth.

Prachi-Kadua River.—The tidal limit seems about the same even although there is now only one mouth in place of several. The tidal effect is noticeable up to 12 miles in the Prachi and 16 miles in the Kadua from the Prachi river mouth.

Debi River.—In 1856 it is remarked that the tidal limit in this river was extending and was 28 miles from the mouth. If measurement was made along the old bends of the river at Machgaon then the tidal limit has remained about the same place, i. e., at Alipingal near Jagatsinghpur, but the length of that tidal channel has extended by over a mile. This river has a very strong tidal action throughout the year. It is certainly not deteriorating. The length of tidal channel is 25 miles following the present course.

Mahanadi.—In 1856 it was stated that the tidal limit was decreasing; that formerly the limit was $25\frac{1}{2}$ miles from the mouth and in 1856 it was only 22 miles. At present it is about 22 miles from where the mouth then was. There is no further proof of decreasing, although the local opinion is that it has decreased from a long time ago. It is well known that the Mahanadi here is far from efficient being divided up into several channels and decrease is not surprising.

Paika.—In 1856 the tidal limit was said to have decreased from a former $28\frac{1}{2}$ miles to $25\frac{1}{2}$ miles and to have deteriorated distinctly as had the Mahanadi. Now it is $23\frac{1}{2}$ miles. Local report, however, does not say that the Paika tidal limit is now less. The river channel above appears to be in much the same condition.

Chitratola.—In 1856 the tidal limit is said to have been 28 miles from the Mahanadi mouth. Nowadays it is about $28\frac{1}{2}$ miles. This river seems in much the same state as then.

Nuna.—The 1856 limit was 28 miles from the Mahanadi mouth and now is much the same.

Brahmini.—In 1856 the limit was said to be $56\frac{1}{2}$ miles from the Dhamra mouth and is now about $51\frac{1}{2}$ miles. There is no local report of any noticeable reduction and the river section seems as good as before.

Kharsua.—The tidal limit of this river was 50 miles in 1856. It is now about 46. It is known from the comparison of cross section that the Kharsua channel has deteriorated due to the increased low spills on its right bank.

Baitarani.—Nothing is known of the former Baitarani tidal limit. There is no report of any change. The present tidal limit is 38 miles from the sea mouth.

Salindi.—No history and no report of change. The tidal limit at present is 20 miles upstream of its outfall into the Baitarani.

Generally speaking it may be said that there is no change in the tidal lengths of the Orissa delta rivers in the last hundred years, so no general deterioration of these rivers is noticeable within tidal limits.

EXAMINATION OF THE APPARENT GROWTH OF THE ORISSA DELTA AND
POSSIBLE FUTURE TENDENCIES.

By an examination of the physical features of the delta, the nature of the rivers, old river courses, soils, coastline, etc., a reconstruction of the delta growth can be attempted. River behaviour and apparent changes can be observed, tendencies noted, and the results applied to the present situation and from this it may be possible to visualise future behaviour.

General observations and assumptions.—A reasonable supposition is that provided the material of denudation remain much the same in the river catchments, the finer materials will be washed away to the furthest distance from the active river water, whether in the sea or remote from the river banks.

Another point is that the bed of a dying river will be gradually filled up with sand, generally coarse sand.

A further point is that the various branches of a parent river have their own silt selective powers depending largely on the relative position of their offtake and the silt load may vary greatly from time to time or have a definite tendency throughout very long periods. The term silt also includes sand.

The delta land-building procedure by delta rivers is well known, the rivers building up the land near their banks, depositing silt to a quickly lessening degree with distance from their banks, abandoning one channel and swinging to another more favourable, and thus constructing a network of ridges and depressions over the delta. In the case where the silt carried in suspension is uniformly fine then the silt will be carried a greater distance from the river and there will not be such a sharp falling off in deposits as there will be with a generally coarse silt charge. Thus we expect and get less differences in general ground levels in a fine silt or clay delta than we do in a sandy delta. To some extent therefore we may judge the nature of a river, dead or alive, by the soil accumulations on its banks and in the neighbouring country. Owing to the very nature of its elevated canal-like structure a delta river will naturally not return in force to its former channel, the old channel remaining as a small high drainage or spill channel.

Bearing the above points in view it is interesting to study the Orissa delta and try to follow the indication of its growth, history, and present tendencies.

The Mahanadi delta.—A study of the contour map of the delta shows that the average ground levels at the very head of the delta is about R. L. 75 to 80. Thereafter the land contours are affected by the usual delta ridge and hollow formation which makes comparison of levels from place to place difficult. Measuring from the head of the delta the 40-foot contour is found to be prolonged furthest down the Mahanadi river line. The 30 foot contour line is much the same distance on all the Mahanadi river group but there is a pocket between the Kusbhadra and Bhargovi rivers and west of the Bhargovi to the Khurda hills. The 20 foot contour line is equidistant from the Debi and Mahanadi and Kusbhadra but there is a reduction north or near the Brahmini, in the Kadua area, the Dhanua

basin, and the Bhargovi-Daya doab. The 10-foot contour line shows a shortening in the Kendrapara area and a big pocket in the lower Daya-Bhargovi area.

The above observations show that the Mahanadi central group of rivers area is the higher, with the Debi a close second. There is a big falling off in the lower Daya, the Dhanua basin, and the Kadua basin. The general spread of the present river system and the marks of the old river ridges indicate that the Mahanadi rivers spread out in an even fan formation from the head of the delta.

The outstanding features in the way of surface sand deposits and high land are along the Mahanadi river and the Prachi. Nowhere else in the Mahanadi delta are such large sand deposits found. The assumption, therefore, is that in the early stage of the delta the two main rivers were the Mahanadi following roughly its present line, and the Prachi branching off from the Mahanadi probably in the line of the Kajuri-Kuakhai with assistance from the Barang river, and proceeding down the present Prachi course.

From the marks of old river loops and the nature of the ground the Prachi seems to have continued to be a fair sized river until the coastline was about 3 miles from its present position. The mid Kuakhai was likely a branch of the Kuakhai-Prachi as the Bhargovi and Kusbhadra rivers seem of old standing.

It is possible that the lower Kusbhadra was a branch of the old Prachi as well as of the Bhargovi and functioned with the Prachi while the coast was about 3 miles inland. The mouth of the Kusbhadra seems to have extended towards Konarakh and not as at present.

The Bhargovi is definitely placed as the next oldest river to the Prachi in the Puri area. It must have entered the sea north of the Samang Pat. Some old and fairly important branches also seemed to have followed the line of the Jagannath road.

The Daya seems a comparatively new river, being an offshoot of the Bhargovi to the low lands on the Chilka side and next the Khurda hills in the corner of the delta.

From the great width of coastal sandhills in the west Puri district, and the general furthest inland discernible old coast line of sandy ridges, it appears that there must have been a comparatively quick rise in coast levels at one period. This rise in coast levels appears to have been general along the delta, and on the map a dotted line has been drawn representing the approximate line of the first obvious rise of the coastline as indicated by the various physical features. This outlines the delta in the early stage when the first series of rises in the coastline becomes apparent by the ridges more or less parallel to the coast. From this outline it seems that the littoral current could not have been so strong in these days.

This rise seems to have been responsible for shutting off the Chilka Lake, diverting the Bhargovi west to the Chilka Lake, shutting off the old Kusbhadra mouth, disturbing the Prachi mouth, shutting off the low Aul area behind sandhills, shutting off the Salindi and causing it to flow to the south, and shutting off a considerable low-lying area near the Matai.

From the map the area just north of Puri is rather indeterminate but it would appear as if the Bhargovi had had its own small delta just where the Kanchi takes off now, and the land between the Sur Lake and Samang Pat and also west of the Samang Pat was part of the projected mouth. The rise of the coast shut off these two depressions and the Bhargovi was diverted to the Chilka Lake and so could no longer build them up as part of its delta. The Bhargovi with its other small branches, and also the Daya, slowly built up the land east of the Chilka Lake and as the course of the Bhargovi lengthened it was forced to adapt itself to these changing conditions of slope by raising its bed and so the Bhargovi as seen to-day is the most elevated channel in the delta. (Part of the rise in bed has also been due to extra silt charge at the head since it has been determined by comparison of old and new cross sections that the bed has risen since 1858).

It would seem as if the Kusbhadra was at first diverted to the east and followed the Kadua channel for some time before it managed to get through the sandhills and form its present course to the sea.

This raising of the coast west of Puri appears to have shut off about a 10 mile stretch of low land behind, in the Brahmagiri area, as well as assisting to form the Chilka Lake. This depression was then under water as far as the Bhargovi delta half way to Puri. The outline of this now low land can be seen from the 5 foot. to 10 foot. contour line downwards.

It is evident from the outline of many other raised sandy ridges parallel to the coast, that several subsequent rises took place or a great deal of cyclonic storm tidal wave debris was suddenly deposited. The spacing apart of these ridges indicate the former ground slope at any particular place. Thus the land from Puri to the Prachi appears to have been steeper than in other places or else the longshore current has washed away the protuberances. The ridges are further apart in the shallow backward areas between the Debi and the Mahanadi and the "back bay" area up the coast from the Mahanadi mouths. Also the pushing out growth of the Dhamra mouth is clearly marked by the coast ridges converging to the north and extending seawards as the river mouth projected.

The growth and development of the Katjuri-Debi river system is not so apparent. It would seem that the original river course was down the Katjuri loop along the Biluakhai and then down the Olanka and also over the country in a series of small delta branches. The area between this river and the Mahanadi seems to have been very evenly dealt with in the building-up process and the silt deposited has travelled a long distance and is fine. The Debi then seems to have developed from the above river by passing down the low land between the Prachi and the old Katjuri river. It has developed a series of loop rivers which pass down the low land east of the Prachi but do not seem to have found conditions sufficiently favourable for them to oust the main river.

The Mahanadi in its upper central half seems to have done most of its work with loop rivers. Only on the lower right bank have a series of distributing spills taken place. As already noted it was said in 1856 that with the deterioration of the Mahanadi and Paika near their junction there was a great tendency for the Mahanadi to develop spill channels to

the south. This was stopped by embankments in the first half of last century. North of the Chitratola the Berupa has followed the usual corner line of low delta land next the original high ground, and numerous spill channels have spilled evenly towards the Brahmini delta lands. There is no sign of any big rivers having gone this way and while the north-west delta lands have been raised high with sandy rich soil the lower areas near Kendrapara are neglected and low. They form part of the "back bay" behind the Mahanadi mouth as Hukitola Bay does to-day and also seem to have received little help from the Brahmini. The solution to this seems to be that this area has lagged behind the central area so much that it was largely submerged and so offered to scope for anything but short channels. This lagging in the building up may have been due to originally deeper levels near the nearby hills and the stagnating effect of intermingled Brahmini and Mahanadi floods as well as the natural radial action of the Mahanadi delta.

On looking at the coastline of the delta to-day it may be wondered considering the above study of the apparent delta growth, why the Dhamra part of the delta projects even further into the Bay of Bengal than the Mahanadi mouth. It seems as though with the projection of the Mahanadi mouth like a spur into the Bay of Bengal the effect of the littoral current became more pronounced and so reduced considerably the rate of land growth here seawards while increasing the rate of deposit in the back bay. The lines of the old coasts north of the Dhamra diverging towards the mouth indicate this to have been a fact and also show the reduction of the divergence when the Dhamra projected beyond a certain distance. The final joining of the Brahmini and Kharsua and later of the Baitarani into one large estuary also ensured a greater driving power of the combined river against any longshore current.

A peculiar formation is the strip of high sand hills, the Hukitola peninsula, forming a spur along the coast north of the Mahanadi mouth. This must have existed for a long time as the hinterland up to the Dhamra river is in a less developed state than anywhere else along the coast, the land being a series of basins between the coast and the Mayapara, and the Mayapara and the Dhamra. This spur of land heading up from the south to the Mayapara mouth is at present wearing away fast in its exposed length. It is not clear how it was projected forward so much when the coast rose.

The Brahmini delta.—The Brahmini on leaving the enclosing hills was confronted with further hills set well back on the south and with high land to the east, so its course lays between these and it appears to have wandered down this mid-course where the Dudhai raised channel arises, and also down its present course. The Kharsua (from its old head) has then broken off at the head of the delta, perhaps from the old Dudhai river, and much later on, the Pattia loop (now the Kharsua head) has developed. The Kimiria also seems to be a newer branch of the Brahmini. The Burha river appears to have run parallel to the Brahmini system at an early date but possibly not joined up until the Kharsua developed between it and the old Dudhai river.

The Brahmini delta must have grown much slower than the Mahanadi delta as evinced by the presence of the Berupa river and the lines of the numerous spill channels from the Chitratola and Nuna towards the

Brahmini area. The Brahmini and the Baitarani deltas appear to have been extended beyond their own natural growth by the Berupa and Mahanadi spill channels and as noted previously, by the backwater silt deposits from the Mahanadi mouth. The advent of the first raising of the coast stopped proper fan-like diversions of the Brahmini mouths into the back bay and so left the large depressions which are found near the Brahmini above the Aul-Kendrapara road. These depressions had not previously been filled up in ridges to any extent as the outfall into the shallow waters of the back bay had tended to give more even general deposits.

The mid and lower Kharsua seems to have been part of the Baitarani delta and of the Brahmini, and its spilling and land-building process on the right bank seems to be extended into the present day although at present exaggerated owing to the construction of the continuous flood embankment on its left bank.

The Baitarani delta.—The Baitarani delta as created by itself, was, as is to be expected from a smaller river, much smaller than that of the Brahmini and before being interfered with by the Brahmini delta, and the Mahanadi and Brahmini river mouth silt being brought up the bay, and by the rise of the coast or the tidal wave debris, its growth can be seen by the fan formation of old ridges and channels terminating roughly along the 10 foot-contour line. The abnormal growth of the flat lands between the 15 foot-contour line and the sea is clearly shown by the contour lines. The effect of this is that the Baitarani in flood comes down the steep part of its own delta and then receives a check at the low lands and spreads its waters broadcast.

The Baitarani still has a tendency in its middle length to throw off side channels and these, being restricted by the continuous right embankment, grow on the left bank. The Genguti branch river apparently had a branch to the north and formed as it still does, part of the Baitarani delta. At present the Genguti is a live river and the Kochila loop of the Baitarani carries the cold weather discharge of the Baitarani.

The Salindi area.—The Salindi is a small river and appears in a network of small channels, its high ground being above the 20 foot-contour. The noticeable feature is how it has swung to the south into the low lands after building up along its ridges.

ALTERATIONS IN RIVERS, ETC., SINCE 1843.

The noticeable physical alterations which have taken place since 1843 are as follows. These are based on comparison of old and new maps and cross-sections of rivers taken in 1858 and recently. Important alterations by human agency are also noted.

Upper Mahanadi and head of delta.—No alteration of importance is noticed in the river course above Naraj. Scour of the right bank in the embayment above Naraj seems slow and continuous and occasional rock falls take place at Rameswar hill into the river. By the construction of flood embankments at Banki and on the left bank of the river in the Orissa States, flood spills have been reduced, but in most cases the Mahanadi can still back up the mouths of the drainage channel and flood a considerable area.

In the 1856 enquiry it was proved to the satisfaction of all concerned that the Katjuri river was taking an ever-increasing proportion of the main Mahanadi flood. The proportion of flood taken by the two rivers in a big flood was then about equal and with the construction of a spur at Naraj in 1858 (later developed into a complete weir across the Katjuri head by 1868) further development of the Katjuri was stopped and the proportion of 1 : 1 has held since then.

The Barang river, which took off from the Katjuri right bank just below Naraj and flowed into the Kuakhai, was cut off by an embankment at its head about 1857 as it showed signs of development and was passing too much flood to Puri district.

Projecting rocky spurs on the Mahanadi left bank in the Naraj narrows and beyond were removed about 1860 by blasting to encourage flow down the Mahanadi. The Mahanadi continues to scour its left bank strongly from $1\frac{1}{2}$ to 5 miles below Naraj.

In 1863 the Mahanadi and Berupa anicuts were started and completed about 1869. Since then, although the pattern of islands in the Mahanadi between Naraj and the anicuts varies, the average river bed levels and flood levels have remained about the same. Rock is found exposed in the Mahanadi bed in places from the left bank about $1\frac{1}{2}$ miles upstream of the Berupa across to upstream of Biranasi spur. There is also of course the exposed mass of rock at Dhubleswar temple island and left bank adjacent. It was noted that in 1858 the Berupa head had so silted up that there was no cold weather discharge. The Mahanadi anicut may have assisted in keeping the Berupa river head from deteriorating.

The Katjuri river has continued so scour its right bank strongly between Naraj and the Kuakhai river offtake. Between 1843 and 1858, when the Naraj weir was constructed, it is reported that about one-third to one-fifth of a mile of the right bank had been scoured away. Since then a further one-half to two-fifth of a mile has gone and the river is tending to widen and become shallower on the opposite left bank. The average bed level appears to have risen a little. A noticeable feature is that while the deep water channel of the Katjuri remains in the same position for the first 2 miles, there is a critical point there at the right bank from which the main channel either swings across to the left bank or continues near the right bank. This change appears to take place after every seven years or so, depending on certain flood stage durations and sequences. At present owing to the continued scour of the right bank at the critical spot it looks as if the river might not return in force to the middle channel.

Between the Dividing embankment and the Biranasi spur embankment there are two small channels and one considerable channel leading from the Katjuri to the Mahanadi. The smaller channels show no signs of improvement but the larger channel shows gradual slow improvement and is moving sideways to the east. A loop channel also takes off the cross channel and joins the Katjuri again further down. It cannot be said that these channels are of any importance at present.

Mahalanobis, as a result of his statistical studies of flood levels, reaches the conclusion that there is no general alteration in flood levels at the delta head and consequently little alteration in the bed levels in general.

Katjuri-Debi river.—Alterations near the head of the Katjuri have been noted above. Below the Kuakhai head there is no great alteration in the river although it is slightly wider below and at Cuttack due to alternate scouring of the right and left banks.

The Surua loop river has been improving at the expense of the Katjuri loop for a very long time. Big breaches in the Surua right embankment in most big floods have been a feature since 1840 and probably previously, and this has accelerated the process of improvement. A comparison of maps and old cross sections of rivers show that since 1858 the average bed width of the Surua has increased from 1,200 to 1,600 feet and the bed has deepened somewhat. The Katjuri loop bed is at present 14 to 22 feet above the Surua bed at the head. During large floods the Katjuri loop temporarily improves somewhat, but the process of deterioration of the Katjuri and improvement of Surua is continuing with consequent re-distribution of the flood discharge. The flood levels however are not rising.

Heavy scour of the left bank of the river below the Katjuri-Surua confluence has been taking place more or less continuously. This is a result of the Surua improvement and Katjuri loop deterioration. The encroachment here since 1843 seems to be about 1,600 feet at the maximum point, and the canal and flood embankment have been retired several times. This process is likely to continue until the improved Surua river reaches its limiting curve round the right angle bend here.

The Biluakhai river seems to be continuing its slow deterioration at the offtake where its bed is at present about 20 to 50 feet above the Katjuri-Debi bed level. The channel on the right of the island, about $1\frac{1}{2}$ miles below the head, is now sanded up nearly to country level. Local bank scour is taking place on the left bank of the left channel opposite.

The Olanka river with its branch the Cross Katjuri were cut off by an embankment from the Biluakhai shortly after 1875 and the Biluakhai left embankment made continuous. Data is insufficient to show any noticeable alteration in the Biluakhai due to this closure. The river now seems adjusted to its small discharge. The Cross Katjuri formerly flowed into the Mahanadi.

The Kandal and Debi bifurcation and channels seem much the same, but the Dahikhai branch of the Debi just below, seems to have deteriorated badly and is moribund at its outfall into the Debi. The growth of the Manikunda breach about $3\frac{1}{2}$ miles from the Kandal head on the right bank has, in the last 15 years or so, caused a deterioration in the lower Kandal channel.

The Alipingal loop of the Debi has continued to improve at the expense of the old Debi river, having increased by 400 to 500 ft. in width and possibly about 10 ft. in average depth since 1858. The extensive and high stone revetment at Alipingal has withstood the river here for more than 50 years but is now being gradually abandoned.

The Taunla river, a loop of the Kandal and Debi on the right bank, has deteriorated somewhat but has continued to scour its left bank and cause trouble for the first half of its course.

A major alteration has taken place in the lower Debi main channel. About 1843 and previously, the main channel followed the right bank as

far as Lataharan village then swung across to the left to Machgaon, swung right again to Osian on the right bank, and continued down what is now called the Nagar Nadi and so to its sea mouth. There were no flood embankments of importance on the right bank and minor river channels developed across the bend until nowadays the main river hugs the right bank straight down to Osian then across to the left bank, rejoins the old main channel below, and so to the sea mouth. The Machgaon channels are now minor channels and the Nagar Nadi is poor. The Debi is still scouring along its right bank in the upper main channel so formed.

As already noted the Debi mouth since 1843 appears to have extended into the sea by about three quarters of a mile.

The Prachi river.—This old river which formerly took off from the Kuakhai about 8 miles from the Kuakhai head, was closed at its head by the Kuakhai left embankment early last century. Even then it was but an insignificant spill channel. Of late years it has received an influx in high floods from the Manikunda breach on the Kandal right bank. The only noticeable alteration is that former sea mouths which existed as shown in the map at the Prachi mouth and the Kadua drainage and creeks on the west, now no longer exist and the Prachi has only one mouth. This appears to be due to the reduction of flood spill into the Prachi area and the natural growth of the sand dunes along the sea shore.

The Kuakhai river.—As already noted, the Katjuri has scoured its right bank above the Kuakhai head to a distance of about half a mile since 1858. The left nose of the Kuakhai head has also been rounded off to a depth of about one-third of a mile. Scour at the right bank head is still severe. The Kuakhai head reach has widened by one-third and the bed appears to have risen somewhat. At present the deepest and average bed level of the Kuakhai are 20 ft. above those of the Katjuri. During a good flood season however the windblown sand at the head of the Kuakhai is scoured away and the Kuakhai starts to flow at a level eight feet below the hot weather bed level.

The scouring away of the high right bank of the Katjuri upstream has opened the country to flood spill at slightly lower flood levels and this flood passes across into the Kuakhai by the old Barang Nadi and other cross spills.

The construction of the railway line with its high embankment about 1893 has confined the Kuakhai to the railway bridge but the river shape seems little altered although scour of the left bank at the bend below the bridges continues gradually.

One considerable alteration observed in the Kuakhai, which has taken place probably about the middle of last century, is that just below its narrows it has joined up on its right bank with the Barang Nadi and so formed two distinct channels where previously only one, the left channel, existed. This has been a bad occurrence as although the left channels is slightly greater, the right channel scours its right bank locally and gives bad sand deposits over the country via two spill channels.

The Kuakhai left embankment above the railway bridge has been abandoned for about 10 years and sand deposits have spread over the left bank. The left embankment has recently been further abandoned for another 5 miles below the railway bridge and the road used as flood embankment.

The Kuakhai right embankment as far as Mancheswar was abandoned in the last part of last century and except for the two spill channels and large sand deposits from the Kuakhai just below the Barang Nadi outfall, there is little difference here.

The Kusbhadra river.—The river has widened at its head by 200 to 400 feet since 1858. The deep channel is much the same.

The Jogisahi revetted flood escape on the right bank about 3 miles below the head was constructed about 1908 and also the Ramchandrapur flood escape just below on the opposite bank. The Jogisahi flood escape breached badly in every big flood until redesigned and reconstructed in 1940.

As far as the big reverse bend in the river at Banamalipur the channel has widened somewhat and also deepened.

The loop spill channel at Athantar at the beginning of this bend was cut off about the middle of last century.

The Bhargovi.—This river has deteriorated as the Daya has improved. In the head reach the river has widened a little but the average bed seems to have risen about 3 feet.

About 5 miles from the head the Achhutpur flood escape was constructed on the left bank about 1905 where a regular breach previously existed. The marginal embankments were raised throughout the Bhargovi in 1856-58.

In the river between the escape and the Kanchi offtake, the width has decreased by about 30 to 50 feet and the bed has risen about 5 feet since 1858.

The draw-off by the Kanchi has increased lately during flood time owing to the construction of the Sur Lake Sea Cut which keeps the lake at a much lower level than previously throughout the flood season.

The north part of the Samang Pat has silted up considerably by the deposits from the Dhauria branch of the Kanchi, and the West Kania Nadi which flows into the Pat from the Bhargovi on the north, is now a very small stream.

The Bhargovi below the Kanchi offtake has also silted up considerably, in some case having a 6 feet rise in bed levels since 1858.

The field and lakeside levels in the exposed area near the Bhargovi-Daya outfall to the Chilka Lake appear to have risen 1 to 2 feet since the middle of last century.

The Daya river.—This river has developed generally at the expense of the Bhargovi. At the head it is 140 to 150 feet wider than in 1858 although the bed levels seem about the same as before. The berms have risen 2 to 3 feet. Considerable scour at the head of the Daya on the left bank has been going on for some years with corresponding silting up of the right bank. This is changing the offtake conditions of the Daya and if this continues the Daya may cease to be the more favoured channel and the Bhargovi may improve.

The three flood escapes at Belmora, Madhipur and Kanti were constructed about 1905 to 1908. Previous to that there was continual breaching of the left embankment in high floods.

In the old maps the drainage and flood spills on the right bank of the Kuakhai seemed to pass largely into the main river about 3 miles above the Daya bifurcation. Now drainage and flood passes straight down south to the Daya.

Between the escapes and Tirimul the river channel has widened by about 140 to 180 feet.

About 1900 the Daya right embankment from Tirimul downwards was abandoned as it was not found possible to confine the big floods between the existing embankments. As a result the Tirimul spill channels on the right bank have enlarged and deepened to river bed level and now take about half the Daya flood water. This flood water returns to the Daya by the Monaguni river further down. Since the development of this spill channel the Daya river bed below the Tirimul spills has risen 3 to 5 feet.

A major alteration in the lower Daya is that owing to alterations at the offtake, the Makra branch has developed at the expense of the Daya such that from being a small stream, part of which returned to the Daya, it now takes twice as much water as the Daya and continues to improve.

The Chilka lake.—Gradual shoaling up of the east end of the lake is taking place. The sea mouth and channel remains about the same but the lake mouth near Sathpara is silting up slowly and constitutes a danger to free outflow.

The Mahanadi river.—The Mahanadi below the Paika offtake at the middle of last century was said to have deteriorated a lot. This seems to be the case.

A noticeable alteration in the course is that while in 1843 the main channel cut across to the Paika near Taldanda and the other channels on each side were minor, now the upper channel is the larger and the lower two channels are minor.

With the apparent improvements of the lower Paika river the Mahanadi right bank below the Paika outfall has been scouring continuously for many years and the canal has been retired here twice, the scour having taken away about 600 feet of the right bank.

Another point of continuous slow scour is on the right bank upstream of the Nuna river outfall where about 400 feet of river bank has apparently gone.

Before the construction of the lower Mahanadi right flood embankment about 1850, and the Taldanda canal flood bank along the whole right bank of the Mahanadi about 1870, the Mahanadi was showing a tendency to develop the spills and channels on its right bank (the Chandpur and Santra rivers). These channels and the flood spill were cut off by the embankment and further deterioration of the Mahanadi from this cause was stopped.

The 1843 maps show the Santra river with a major loop channel to the Mahanadi mouth now scarcely discernible. The Santra is now purely a tidal creek and its own direct sea mouth is closed although occasionally opened temporarily by a cyclone.

As noted previously, the Mahanadi mouth has extended since 1843 by about $2\frac{1}{2}$ miles in a north-easterly direction although the direct seaward growth of the mainland is only about 1 mile. The main channel is now more clearly defined near the mouth.

Hukitola Bay has silted up considerably and the Hukitola spur peninsula extended, although it scarcely seems that the position of the peninsula in the 1843 map can be correct as the refuge house on the present peninsula is of long standing.

The Paika river.—The Paika river, which is a loop of the Mahanadi, is generally considered to be improving slightly at the expense of the Mahanada. Satisfactory proof is not to hand. It appears that in low floods the Paika improves and in high floods the Mahanadi clears itself and the Paika silts to some extent. It seems to be an improved channel in its lower reach. It is continuously [scouring its left bank just above its outfall.

The Chitratola river.—There is little difference noticeable in this river although the probability is that it has deteriorated in depth a little below the Nuna off-take and further down. The channel on the left of the long island above the Nuna bifurcation at Kendupatna is deteriorating. The Chitratola head at the Nuna bifurcation is being gradually scoured downstream and appears to have travelled about 600 feet since 1843. Further scour here may alter the silt and consequently flood distribution between the two rivers.

The Nuna river.—This river appears to be improving as it has been scouring its banks for many years and altering its meanders. There is insufficient proof of any deepening of the bed. It is slightly wider at the head.

With the construction of the Kendrapara canal and flood embankment along the left bank of the river about 1870, all flood spill and small channels on that side were cut off. The Nuna river bed below the Pothi offtake seems slightly higher, and the Pothi river, a loop river of the Nuna on the right bank, is improving.

There are some alterations in the Pothi river, now a loop of the Nuna on the right bank. Formerly its chief offtake was at Jalpoke about $1\frac{1}{2}$ miles below its present head which was then a less important channel. The Jalpoke head has now silted up. Also in 1843 the Pothi was an inland spill channel which joined the central drainage but since then it has become a loop channel of the Nuna as seen in the map. The Pothi river seems to have deepened its bed considerably but there is little increase in width.

Just above the junction with the Chitratola, the Nuna, in the last twelve years, has cut off the bend and joined the Chitratola a quarter of a mile further upstream.

Two spill channels have been cut off on the left bank of the Nuna near the Chitratola junction by the construction of the canal embankment. The left loop of the Nuna below this is a development not shown in the old maps and is improving at the expense of the right loop.

Gobri or Jambu river.—This central drainage channel has altered its course for a few miles as shown on the map. The former small creek joining it with the Nuna river at Mahakalpara has recently opened up again since the canal and flood bank to Jambu has been abandoned and breached.

The Berupa river.—The Mahanadi and Berupa anicuts were constructed about 1869. As previously mentioned, the construction of these anicuts possibly prevented deterioration of the Berupa river.

The Chota Genguti river on the left bank of the Berupa was cut off at its head by an embankment about 1875.

The Bara Genguti branch of the Berupa is the main river and has been and still is developing steadily at the expense of the Berupa which is now less than half the size of the Genguti channel.

The outfall conditions of the Berupa into the Kimiria has changed considerably since 1843 as the map shows. Formerly the Kimiria river continued down the Kelua, and the Genguti-Berupa joined it above Indipur. The Berupa also had a small channel into the Kimiria at the Kelua head. Since then the Kimiria has abandoned the Kelua channel which is now insignificant and has taken over the Berupa channel.

The Brahmini river.—There is no noticeable change in the Brahmini above the railway bridge. The river continues to scour its right bank $1\frac{1}{2}$ miles upstream of the bridge.

The big alteration is at the Pattia-Kharsua bifurcation from the Brahmini. In 1890 the Brahmini and Pattia anicuts were constructed and prior to that the Kharsua river, which took off mid way between the present Brahmini and Pattia bifurcation, was cut off at its head by an embankment. At this time the Kharsua was said to be improving at the expense of the Brahmini. Subsequent to this and prior to the construction of the anicuts the Pattia river took the part of the Kharsua and developed in its upper reach, removing the island which masked its head.

The Brahmini has shown a steady deterioration up to recent times. Many big spill channels opened on its left bank downstream of the Pattia offtake but these have been closed since 1933, and one high level revetted escape allowed just below the anicut. The anicut which was largely sanded up except on the left bank has been demolished wherever it was exposed and the river now seems fairly steady, with the deep channel on the left bank slightly improved.

At the Kimiria-Brahmini bifurcation the Kimiria head is widening as its left bank scours and there has been strong scour of late. The Kimiria is perhaps improving slightly at the expense of the Brahmini but definite proof of this is lacking.

The Brahmini and the Kimiria have deteriorated since 1858 and a comparison of some river cross sections indicates a general bed rise of about 4 feet until the tidal limit near Indipur is reached. *The evidence of this 4 feet rise is not sufficiently widespread to be considered quite satisfactory.*

The loop spill channel on the mid Brahmini right bank as seen on the map has now deteriorated to negligible proportions. The big bend in the Brahmini just above the junction with the Kimiria was cut off about 1933 and is now largely moribund.

In the tidal reaches of the Brahmini several alterations have taken place as shown on the map. The most important is the narrowing of the neck of land between the Kharsua and Brahmini above their junction and the extension of this neck of land southwards with corresponding heavy erosion on the right bank into the Hansua river head. The narrow neck of land between the Kharsua and Brahmini has been reduced from 1,800 feet to 650 feet and the right bank erosion at the Hansua has eaten away half a mile and developed a cut-off channel to the Hansua river.

The Mayapara branch of the Brahmini to the sea shows some alteration in its bends and some silting at its head. Off its mouth three new islands have appeared between 1920 and 1930. The river mouth has extended but little.

The Hansua river.—This river has developed a cut-off channel to the Brahmini as above mentioned and thus shortened its course to the sea by $3\frac{1}{2}$ miles. It is developing continuously by deepening its bed and undermining its banks.

The Pattia-Kharsua.—The construction of the anicut and alteration in head have already been described under the Brahmini river heading. The only other major alteration in course is the cutting off of the Kanika loop in the tidal reaches as shown in the map, and the extension of its junction with the Brahmini as already noted. The Burha-Kharsua continuous left embankment was constructed with the Burha and Baitarani anicuts in 1870-72.

The upper Kharsua seems to have widened somewhat but there is no proof of bed alterations.

The mid Kharsua has deteriorated badly owing to the numerous spills channels developing on its right bank such that the width in places has reduced from 600 to 400 feet and in some places the bed is raised about 3 feet. The Similia, Tanti, and Palasahi spill channels on the right bank of the Kharsua were revetted at their head to form low level flood escapes, probably at the beginning of this century. A noticeable reduction has been caused in the river section below since the Rautra Ghai, upstream of Binjharpur, has remained open since 1926.

The Kharsua channel downstream from above Aul, where the general flood spill largely returns to the river over its right bank, remains in very good condition.

The Burha river.—The Baitarani and Burha anicuts as also the continuous embankment on the Burha and Kharsua left bank were constructed in 1870-72. The Burha river was observed to be increasing at the expense of the Baitarani. The anicuts have lessened this tendency but it is still there as the Burha anicut is slightly lower in level and has more sluiceway than the Baitarani anicut.

The Jamuna river on the right bank of the Burha some $2\frac{1}{2}$ miles below the anicut has increased, although at present it seems fairly steady. It now takes most of the cold weather flow of the Burha.

The Baitarani river.—The upper Baitarani left and right embankments and the lengthy right embankment below the anicut were constructed or reconstructed with the Burha and Baitarani anicuts and irrigation schemes about 1870-72.

The right loop of the river a few miles below the anicut, has been steadily deteriorating and the left loop improving. It is possible that this left channel was formerly the Genguti river head. There is also a suspicion that the Genguti branch river on the left bank below Jajpur has been increasing slowly at the expense of the Baitarani.

The Kochila loop river is improving slowly at the expense of the main Baitarani and now takes the cold weather flow.

GENERAL DEDUCTIONS FROM THE STUDY OF THE HISTORY OF THE DELTA AND ITS RIVERS.

Certain general deductions may be drawn from the above account of the delta and its rivers. These may be possibly qualified by the use of training works and other causes entered into elsewhere.

The Mahanadi delta and its rivers appears to have developed as an almost free delta formation subject to certain restrictions such as the slowing up of its growth by the strong littoral current, the sudden uprising of the coast at one period with its effects on the hinterland and river courses the chief being the diversion of the Bhargovi river to the Chilka Lake, and the unnaturally quick growth of low lands on the north-east caused by the littoral drift up the Bay of Bengal and also by the Brahmini delta slight interference. The tidal limits appear to be much the same as in last century. Although some river beds have risen and other lowered, average bed levels are much the same as in last century and the average flood levels have not risen although flood distribution has altered. As such the present Mahanadi system may be considered as fairly stable.

Certain alterations in the relative growth and deterioration of the rivers are indicated. The importance of the relative silt charge at the head of a branch river as affecting its future weal is demonstrated by many cases. The present favoured channels seem to be the Katjuri-Debi the Nuna, and possibly the Paika. All of these are in favourable situations to continue as good channels provided there is no great alteration of silt charge at the head. The Daya is in need of control from Tirimul to the Chilka lake via the Makra. The Bhargovi, if given an outlet near the Sur Lake, should become a more efficient river improving its capacity and lowering its bed. The Kusbhadra may improve somewhat but not to any great extent as it is old and small. The Prachi cannot be resuscitated as a good river. The continual erosion of the Katjuri right bank between Naraj and the Kuakhai, with heavy scour at the Kuakhai head is disturbing as altering the head of the Kuakhai and possibly affecting its discharge in the future. The Katjuri-Debi will continue its tendency to work its way westwards into the land. The Mahanadi cannot be expected to improve in its lower middle reaches. The Paika is likely to continue to improve slowly at the expense of the Mahanadi. The Chitratola below the Nuna off take is likely to deteriorate slowly and the Nuna to increase and form a more efficient channel. The Pothi loop river is likely to improve at the expense of the Nuna.

The Brahmini delta has not developed freely but has been interfered with on one side by the Mahanadi delta on the other by the Baitarani

delta, and across its face by deposits from the Mahanadi and by a rise in the coast. The Kimiria loop branch is likely to develop at the expense of the Brahmini loop. The Brahmini river generally is not likely to get any better.

The Hansua river is likely to increase up to a certain stage as the Brahmini and Kharsua river cut into the land opposite their junction, but later the Hansua head will not be in so favourable a position and if the sea continues to break through the Hukitola Isthmus the Hansua mouth may also be affected.

The Pattia-Kharsua river is a good going river not so old as the Brahmini and the general line is good but it is in a bad position from the Kani Nadi offtake to Aul, and improvement there seems difficult.

The Baitarani is not capable of much improvement. Its Genguti branch is not likely to improve at present. The Kochila loop channel will continue to improve at the expense of the Baitarani.

If the sea continues to scour away the coast just north of Hukitola Bay then eventually it will break through into the low lands and creek behind and the Mayapara mouth may be partly closed and the newly formed Wheeler Islands be washed away again.

Generally speaking, the combined deltas seem to be in a fairly stable condition as evinced by their past history and present condition and so may be amenable to training and extensive flood control.

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APPENDIX IV.

Comparison of Mahanadi, Godavari and Kistna deltas and rivers.

The Godavari and Kistna deltas and rivers were inspected and studied to determine whether the rivers of the Orissa delta were similar in features to these Madras rivers. If that was the case then it would be possible to confine the floods of the Orissa rivers within double marginal embankments to near the sea as has been done in the Godavari and Kistna rivers for ninety years with no apparent ill effects.

The first important point is whether conditions in the Godavari and Kistna deltas are satisfactory, i. e., have the river floods been satisfactorily controlled and does it appear that the confinement of these rivers has not resulted in the raising of their beds and flood levels with time. Both the Godavari and the Kistna floods are completely confined within double marginal embankments since 1853—55 with no apparent progressive rise in flood or river bed levels and with no consequent necessity to raise the flood embankments. Trouble is experienced by scour of the river banks at places but this is local and to be expected and the rivers are not "swinging" in any way. The situation as regards control of flooding without deleterious effect on the river or embankments is fully satisfactory.

A comparative statement of the features of the Mahanadi, Godavari and Kistna is attached from which the following points may be emphasised.

The Mahanadi obviously has a greater intensity of rainfall in the catchment than the Godavari or Kistna as the discharge is so much greater in comparison with the catchment area. The typical flood season curves indicate that the duration of high floods is much the same though for the Mahanadi it is possibly longer. The Godavari is different however in that it gets additional small floods in October and November due to the south-east monsoon and its minimum discharge of 1,500 cusecs is not so small as the 200 and 100 cusecs of the Mahanadi and Kistna.

The Mahanadi flood slope is 1.6 feet per mile against approximately 1.17 feet per mile for the other rivers. The straight fall from M. F. L. at the delta head to the sea is 1.67 feet per mile for the Mahanadi, 1.39 for the Godavari and 1.36 (1.43 in the extraordinary flood of 1903) for the Kistna.

The Mahanadi delta is larger than the others and the river branches are much more numerous. The loop rivers so prevalent in the Mahanadi delta are not found in the others. The Godavari and Kistna deltas and river banks are generally hard black soil. Only in the mid Debi river of the Mahanadi system is hard black soil found to any great extent and this generally has about 10 feet covering of lighter soil. The tidal limits in the Mahanadi, except in the clayey Debi, are less than in the Godavari and Kistna.

The average bed sand of the Mahanadi system is smaller than that of the other rivers and the occurrence of gravel is less.

In my opinion there is no good comparison between the Mahanadi system and that of the Godavari and Kistna. The chief noticeable difference is the nature of the general soil of the delta and consequently of the river banks and to a large extent of the bed material also. Where hard black soils occur as in the mid Debi there is a distinct resemblance to these two Madras rivers, i. e., a deep trough-like section between high stiff clay banks. The difference in character of these rivers and their deltas with the Mahanadi is fundamentally the different nature of silt and silt charge which has been coming down these rivers from the beginning. The Kistna and Godavari bring fine washings from black soil catchments with a certain amount of coarse sand and gravel whereas the Mahanadi catchment washings are mainly fine to coarser sand.

The Godavari and Kistna have a better hydraulic section which makes up for their smaller slope. Although their M. F. L. is higher over the banks than the Mahanadi this is caused by the confinement of the flood within the embankments. The Mahanadi is the shallowest channel of the three. The monsoon flow of the Godavari and Kistna is concentrated between their high banks while the Mahanadi flow is often dispersed. The result is that the Godavari and Kistna even with less fall per mile have a better bed cleansing power and dispose of their bed silt which is coarser than that of the Mahanadi.

While not being able to strike an exact parallel with the Godavari and Kistna, which appear largely to have taken their present desirable form naturally and not due to embanking, the present state of these rivers offers every encouragement for such a state in the Mahanadi system especially where the natural features such as hard soil and high banks occur. Application in other cases is doubtful.

Detailed reports on the Godavari and Kistna rivers and deltas have been prepared and placed on record.

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Comparative features of the Mahanadi, Godavari and Kistna rivers.

Item.	Unit.	Mahanadi.	Godavari.	Kistna.
Catchment Area ...	Sq. miles	51,000	115,000	97,050
Length of river to delta head.	Miles ...	466	860	750
Length from centre of catchment.	Miles ...	260	805	802
Total average rainfall in catchment.	Inches ...	34 (July to September).	Not known ...	Not known.
Maximum discharge ...	Cusecs ..	1,571,000	1,500,000 to 1,927,000 doubtful.	1,060,880 in 1908. 770 000 usual maximum.
Minimum discharge ...	Cusecs ...	200	1,500	100
Flood rise in monsoon	Feet ...	25	80	85
Average distance delta head to sea.	Miles ...	55	40	50
Angle included by delta	Degrees ...	93	169	114
Area of delta ...	Sq. miles	2,940	1,955	2,110
Number of main branches near head.	...	2 branches at head and 4 within 9 miles of head.	2	Nil.
Number of separate branches to sea.	...	6	4	4
Maximum width of river above delta.	Miles ...	2.1	4.2	2.4
Minimum width of river above delta.	Miles ...	0.4	1	.5
Width of main branches near head.	Miles ..	0.6, 0.4, 1.2, 0.2	1.8 to 1.1	No branches. Main stream 1.2.
R. L. of river bed at delta head.	R. L. ...	68.0	81	89
R. L. of M. F. L. at delta head.	R. L. ...	92.2	55.6	70.55 ordinary maximum 68.0.
Average flood slope above delta.	Ft/M1 ...	2.21 to 1.62	1.21	1.17
Average flood slope in delta to tidal limit.	Ft/M1 ..	1.68 to 1.21	1.12 1.19	1.17
Do. in tidal reaches.	Ft. ...	0.88	1.0	0.95

Item.	Unit.	Mahanadi.	Godavari.	Kistna.
Tidal limit from sea ...	Miles ...	22 to 28	25 to 30	24
Average depth of channel below banks near delta head.	Ft. ...	18	19	15
Deepest scour below banks excluding tidal reaches.	Ft. ...	61	56	36
Height of M. F. L. over average banks outside tidal reaches.	Ft. ...	4.0	5.8	11.0 in 1903, 8.0 ordinarily.
Average surface velocity	Ft./Sec. ...	5.5	4.25	7.5 (doubtful, average less).
Nature of delta soil	Sandy loam in upper river half, clayey in lower areas, and black soil in some areas.	Uniform hard black soil with lighter black soil occasionally.	Uniform hard black soil with lighter black soil occasionally.
River bank soil above delta.	...	Sandy and sandy loam.	Hard black soil.	Hard black soil.
River bank soil within delta.	..	Sandy loam and light clay with hard black soil below in some branches.	Hard black soil with occasional made-up silty bank.	Hard black soil with occasional made up silty bank.
Average size of bed sand	Millimetres	0.42	.48	.48
Size and prevalence of large bed material.	..	Very occasional grit up to 2 mms. and very occasional gravel from $\frac{1}{8}$ " to $\frac{1}{2}$ " and 1".	Occasional grit up to 2 mms. and occasional gravel $1\frac{1}{2}$ " $\frac{3}{4}$ " and $1\frac{1}{4}$ ".	Occasional grit up to 2 mms. and frequent gravel $\frac{1}{2}$ " to $\frac{3}{4}$ " and 1".
Anicuts or weirs on rivers.	..	Delta head rivers all controlled by three separate anicuts.	Two main branches controlled at bifurcation by four anicuts.	One anicut across main river at delta head.
Extent of flood embanking.	...	Scattered system of embankments, some double, some single, some continuous, some intermittent.	Double marginal embankments to within a few miles of sea.	Double marginal embankments to within a few miles of sea.

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APPENDIX V.

Action taken on the recommendations of the Orissa Flood Advisory Committee as laid down in the Second Interim Report, para. 24.*1. Channel from Dhanua Right Embankment at Siaro to Dal Nadi at Tarhana and repairing the Dhanua Right Embankment.*

Two estimates were drawn up for the work, viz., one for raising, strengthening and breach closing the Dhanua right embankment and the other for the construction of the channel from the Siaro to Tarhana and closing the Dal Nadi so as to restrict flow into the Sur Lake only. Government approved of the estimates for Rs. 4,064 and Rs. 45,400 respectively. The approval having been received too late the works could not be taken up prior to the 1941 floods. Afterwards there was objection from the landowners to give land free of cost and correspondence is still going on for obtaining land free.

2. Preparation of design for escape on the Bhargovi river left bank at Gobakund and channel from there to the Sur Lake.

Levelling was done and a rough estimate amounting to Rs. 3,17,000 was drawn up consisting of Rs. 2,62,000 for the channel, a lump sum of Rs. 40,000 for the escape or sluice and 5 per cent for contingencies. An ordinary escape was out of question as the drop in level would be too great. After further consideration of the flood details and financial aspect of the scheme, it was held up until further general investigation was concluded. During the 1942 meeting of the Orissa Flood Advisory Committee the Committee have advised preparing an estimate for improving the Kanchi head by construction of a channel from the Bhargovi to the Kanchi from near the 27½ mile of Bhargovi left to ½ mile of Kanchi right. This latter improvement will cost little and the Gobakund out is to be held in abeyance.

3. Construction of masonry sill in the Sur Lake Sea Cut.

Government sanctioned and finally approved the estimate of Rs. 20,000 for constructing a masonry sill at R. L. 7. 0. The work is in progress there being some delay due to non-availability of railway wagons for carriage of rubble from quarries. The sill portion is nearly completed, only flank revetments and approaches remain to be done. The Committee have now advised having the central 200 feet of the sill at R. L. 3.00 instead of at R. L. 7.00 and pending design of this central portion the remaining unconstructed 100 feet of the central 200 feet has to be filled up temporarily with rubble only.

4(a). Raising and strengthening Kusbhadra embankments and extending to the sand hills near the coast.

Executive Engineer Southern, submitted estimates for repairing and strengthening the existing Government embankments in the upper reaches. The estimate for the right embankment is sanctioned for Rs. 32,430 but no allotment given. The estimate for the left embankment is under revision. The rough cost of the remaining works to the sandhills amounted to Rs. 436,700 including Rs. 15,000 for escapes and sluices in the proposed

embankments. The Committee have reaffirmed their opinion about construction of these embankments in their February 1942 meeting. Survey is now in progress for the preparation of detail estimates for the work.

4(b). Closing the eastern loop of the Kusbhadra near Bedpur.

This will be taken up along with item 4(a) above.

5(a). Investigation for confining the Katjuri-Debi river to a single channel.

Cross sections and contours, etc., were put before the Committee in their February 1942 meeting and after considering the flood situation they have now recommended extending an embankment along the Kandal right bank, closing the Taunla river head and joining up with the existing Debi right embankment and continuing this to the Taunla outfall.

5(b). Taking over and reconstructing the private embankment on Katjuri right bank from Gobindpur to Manikunda.

The detailed estimate is under preparation by Executive Engineer Southern Division.

5(c). Extending an embankment between 1B and 2B embankments on the Debi right bank in Kakatpur area.

The estimate for the scheme as modified by the Orissa Flood Advisory Committee in their 1942 January meeting has since been completed by the Flood and Drainage Division and amounts to Rs. 86,000.

6(a). Closing the breach at Tirimul on the Daya river and constructing a high level escape.

An estimate had been drawn up for controlling the breach, consisting of Rs. 1,750 for flank embankments and Rs. 16,000 for the escape. A large sluice with 3 openings and automatic tipping shutters would cost about Rs. 4,000 but would not be so desirable. After further investigation and discussion the Orissa Flood Advisory Committee have now advised closing or restricting the Tirimul breach and providing a continuous right embankment from above Tirimul to near the Monaguni junction. Before deciding the question whether this breach should be closed totally or simply restricted, further study of flood data is required.

6(b). Restoration of lower Daya left embankment.

Estimate for the work amounting to Rs. 15,805 has been sanctioned and work nearly completed.

6(c). Linking the Bhargovi left embankment with the Nuna salt embankment at the Chilka lake.

No action has yet been taken on this.

7. Investigation for flood control of the Brahmini-Kimiria area.

Flood data were collected and recorded and put up before the Committee in the 1942 February meeting. Their recommendations are to be found in that Third Interim Report. General investigations are however to be continued which is being done by Executive Engineer, Flood and Drainage Division.

8(a). *Cancelling the former proposals to remove the Gajaria and Uttikan embankments.*

The matter has been dropped as recommended.

8(b). *Preparation of comprehensive flood protection scheme for the Brahmini-Kharsua area.*

Data and the results of further investigations were put before the Orissa Flood Advisory Committee and recommendations subsequently made in their Third Interim Report.

8(c). *Hansua Creek Investigation.*

Data collected were put up before the Committee in January 1942. Investigation is to be continued and put up later.

9. *Acquiring statutory powers for levying protection cess.*

The matter of revision of the embankment laws including the realisation of cess has been discussed with the Civil Department and is under consideration by Government.

J. SHAW,

Secretary, Orissa Flood Advisory Committee

February 1942.