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VERNON-HARCOURT

ON

THE RIVER HOOGHLY.

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BY

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WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

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"The River Hooghly."

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

RIVERS on approaching their outlet may, in general, be divided into two distinct classes, possessing different characteristics, according as the sea into which they flow is tidal or tideless. Rivers flowing into a tidal sea receive during every flood-tide an influx of sea-water, which being added to the volume of land-water, increases correspondingly the total discharge during the following ebb-tide, and the size of the outlet channel; whereas, rivers flowing into a tideless sea are wholly maintained by their fresh-water discharge. Again, tidal and tideless rivers exhibit two different types of outlet, owing to differences in their physical conditions. Thus, occasionally tidal rivers flow straight into the sea, with only a moderate increase in their width, as for instance the Tyne, the Yare, the Adour below Bayonne, and the Nervion; whereas, more commonly they emerge into wide, expanding estuaries before reaching the open sea, as in the cases of the Thames, the Ribble, the Seine, the Gironde, the Weser, the Elbe, and the St. Lawrence. Some tideless rivers, also, flow into the sea through a single mouth, as exemplified by the Trave, the Duna, the Neva, and the Dnieper; whilst most of the large tideless rivers, by depositing in the mass of still sea-water at their outlets the large quantities of alluvium they carry down, form continually advancing deltas, across which they pass in several diverging branches to the sea: such rivers as the Danube, the Volga, the Nile, and the Mississippi are well-known examples.

The above classification comprises the four ordinary types of outlets of tidal and tideless rivers; but an unusual combination of physical conditions may produce an exceptional type of river-outlet, occupying a sort of intermediate position between tidal and tideless rivers, in possessing some of the characteristics of both, as well illustrated by the deltaic Ganges flowing into the tidal Bay of Bengal. The River Ganges, draining a basin of 470,000 square miles, brings down such large quantities of sediment in its waters that, notwithstanding the existence of a tidal rise, at ordinary spring-tides, of 9¼ to 11 feet at different places in front of its mouths, it has formed a delta having a sea-face of about 250 miles, through which it flows to the sea by a number of branches. This river, accordingly, exhibits the peculiar conjunction of conditions of being tidal for many miles above its outlet, and terminating in a delta, like most large tideless rivers. The marked contrast thus presented by the outlet of the Ganges to the ordinary types of river-outlets, invests it with a special interest, as an instance of a river-outlet governed by an exceptional combination of physical conditions. Materials are not available for any general description of the delta of the Ganges; but numerous surveys of its most western branch, known as the River Hooghly, which have been made within the last 21 years between Calcutta and the sea, enable a fairly complete investigation to be made of the navigable condition and recent changes of this branch below Calcutta, which constitutes the principal navigable outlet of the Ganges, and the approach channel to the capital of India.

An interesting sketch of some of the physical characteristics of the Hooghly was given[1] by the late Mr. J. A. Longridge, M. Inst. C.E., in a Paper on "The Hooghly and the Mutla," read in 1861; but the main object of that Paper was, by means of a comparison of the relative natural navigable conditions of the River Hooghly and of the old abandoned outlet of the Ganges, known as the River Mutla (Fig. 1, Plate 2), to advocate the adoption of a new port for Calcutta, subsequently called Port Canning, at the upper end of the Mutla, connected with Calcutta by the Calcutta and South Eastern Railway, of which he was the engineer, as a safer and more readily accessible route than the Hooghly for sea-going vessels. Moreover, until Mr. E. W. Petley, C.I.E., inaugurated, in 1882, a regular system of periodical surveys of the Hooghly, and the production from them of large-scale charts of the river, little reliable information existed as to the condition and changes of the river, beyond the small-scale Admiralty charts partially corrected, at long intervals, from Lloyd's survey of 1836.

In 1896 the Author inspected the Hooghly from Barrackpur, about 13 miles above Calcutta, down to the sea, spending several days on the river; he also visited the site, on the right bank of

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 2.

the Ganges, of the inlet of the Bhagirathi, the most western and the principal feeder of the Hooghly; and he subsequently studied and compared all the charts in existence at Calcutta, and copies of the charts of the river of 1836 and of the sea-face of the Ganges delta of 1837–40, lent to him by the Hydrographer, for his "Report on the River Húgli"[1] to the Commissioners for the Port of Calcutta, dated December, 1896, and published at Calcutta in the following year. Moreover, in compliance with the Author's request, for the preparation of this Paper the Commissioners have very kindly sent him copies of all the printed large-scale charts of the Hooghly issued by the Survey Department of the Commission since 1896. These comprise a complete survey of the river from Munikholi Point, about 10 miles below Calcutta, down to the sea, made in 1900–1902 (Fig. 7, Plate 3, and Fig. 16, Plate 4), together with surveys, at earlier periods, of the river between Hiragunj Point and the estuary, and also of the estuary, which have enabled him to bring the history of the river down to 1902.

Physical Characteristics of the River Hooghly.

Sources.—Three overflow-channels, known as the Nadia rivers, forming the first deltaic offshoots from the River Ganges, lead the flood-waters of the Ganges into the Hooghly, which is considered to commence at the confluence of the two most western channels, the Bhagirathi and the Jellinghi, opposite Nadia, about 79 miles above Calcutta; whilst the third channel, the Matabanga, issuing from the Ganges a few miles to the east of the Jellinghi inlet, enters the Hooghly about 30 miles below Nadia (Fig. 1, Plate 2). The Hooghly, however, does not derive the whole of its fresh-water discharge from the outflow from the Ganges into these three channels; for the Bhagirathi, whose supply from the Ganges is approximately equal to the combined discharges of the Jellinghi and Matabanga, receives on its right bank, owing to its constituting the western boundary of the Ganges delta, the drainage of about 8,700 square miles of country lying to the west of it, mainly through four principal tributaries, the Bansloe, the Dwarka, the Kana, and the Adjai (Fig. 1, Plate 2). Moreover, lower down, the Hooghly itself has its fresh-water flow augmented by the drainage from the

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[1] The spelling which appears on the charts has been followed for the place-names; the long-established form "Hooghly" has, however, been adopted for the name of the river which forms the subject of this Paper.—Sec. Inst. C E.

lands on its west side, brought in, on its right bank, chiefly by the Damuda, joining the Hooghly 37 miles below Calcutta, the Rupnarayan coming in only 5 miles lower down, and the Haldia and the Rasulpur flowing into the estuary of the Hooghly about 68 and 87 miles, respectively, below Calcutta (Fig. 2, Plate 2). The Hooghly, is therefore not merely a deltaic branch of the Ganges, but also, like an independent river, carries down the drainage from about 25,000 square miles of land lying between the western range of hills and its own and the Bhagirathi's right bank; and if the deltaic tract of country to the east, draining into the Nadia rivers and the Hooghly, is included, the drainage-area of the Hooghly, irrespective of the supply from the Ganges, approximates in extent to the Seine basin of 30,000 square miles.

Flood-Season.—The high-flood rise of the Ganges opposite the inlets of the Nadia rivers, resulting largely from the melting of the snows on the Himalayas, corresponds very closely with the rainy season, lasting for about 4 months, from July to October, when the Ganges receives a large accession of flood-waters from all parts of its basin, and the tributaries of the Bhagirathi and the Hooghly are subject to periodical floods. Consequently, during about one-third of the year, the River Hooghly discharges large quantities of flood-water, which scour out its ebb-channel and raise its water-level; whereas during the remaining 8 months of the year, its fresh-water flow becomes so small that the maintenance of its navigable channel and available depth are practically wholly dependent upon the influx of tidal water from the sea.

Formation of an Estuary.—The deltaic branches of tideless rivers are proportionate in size to the volume of water which they discharge, and by which alone their channels are maintained. The Hooghly, on the contrary, owing to tidal influences, expands beyond Kantabaria, about 55 miles below Calcutta, into a widening estuary encumbered by sandbanks, through which it flows to the sea (Fig. 2, Plate 2). The existence of this estuary, which has evidently been moulded by tidal action, aided by the shiftings of the channels, amidst the mass of deltaic alluvium from the Ganges, presents considerable interest, as clearly indicating that the natural form of the outlet of a tidal river is an expanding estuary, wherever its banks are composed of materials readily eroded by currents and waves.

Fresh-water Discharge into the Hooghly.—Notwithstanding the frequent alterations in the situation and form of the inlets of the Nadia rivers, the flood-discharge of the Ganges into these rivers does not appear to vary very considerably, judging by the approximate uniformity of the cross section of the Bhagirathi at Berhampur during recent years. The flow of water received by the Hooghly from the Ganges through the three Nadia rivers ranges from about 200,000 cubic feet per second during the height of the floods (*i.e.*, between the latter part of July and the beginning of October), down to almost nothing during the lowest stage of the Ganges, throughout the 4 months from the end of December till the end of April, when the inlets from the Ganges are dry. The discharge from the rivers draining the country lying to the west of the Bhagirathi, between its right bank and the hills, is much more irregular during the rainy season than the influx from the Ganges, reaching a maximum of 300,000 to 450,000 cubic feet per second during high floods, which come down from the hills about once a month in the rains, and last 3 or 4 days; and falling to an average discharge of about 70,000 cubic feet per second during the remainder of the rainy season.[1] When exceptional floods passing down the tributaries of the Bhagirathi coincide with a maximum influx from the Ganges into the Nadia rivers, the discharge of the Hooghly past Calcutta may attain to a maximum of about 650,000 cubic feet per second. During the dry season the inlets of the Nadia rivers are above the level of the Ganges, and the tributaries of the Bhagirathi become dried up; but owing to the percolation of water from the land through the banks and bed of the rivers supplying the Hooghly, a small flow of fresh water takes place past Calcutta, which has been estimated at 20,000 to 50,000 cubic feet per second between November and June.[2]

Fresh-water Discharge from the Rivers Damuda and Rupnarayan.— The fresh-water discharge of the River Hooghly is nearly doubled below Hooghly Point by the waters brought into it by the Damuda and Rupnarayan, opposite Fulta Point and Hooghly Point respectively (Fig. 2, Plate 2), from the drainage of an extensive tract of land to the west, between the right bank of the Hooghly and the hills constituting the boundary of the basins of these rivers. The combined discharges of these rivers into the Hooghly during high floods reach a maximum of nearly 700,000 cubic feet per second.[3] During the dry season the flow of these rivers becomes

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[1] H. Leonard, "Report on the River Hooghly," p. 5. London, 1865.

[2] *Ibid*, p. 6.

[3] H. Leonard, "Memorandum on the River Hooghly," p. 3. (*Records of the Government of India* (*P.W.D.*) .*No. 45.*) Calcutta, 1864; and O. C. Lees, "Report on the Damooda-Roopnarain Survey," pp. 7 and 8. Calcutta, 1890.

very small; and at this period a bar of sand emerges across the mouth of the Damuda at low water of spring-tides, and the Rupnarayan has a depth of only 3 feet at a short distance above its mouth. Accordingly, the fresh-water discharge of the Hooghly below the confluence of the Rupnarayan may vary between a maximum of about 1,350,000 cubic feet per second during the height of the rainy season, with the coincidence of a high rise of the Ganges with heavy floods in the tributaries, and to a minimum of about 21,000 cubic feet per second towards the close of the dry season.

Tributaries flowing into the Hooghly Estuary.—The River Haldia, rising in the hills to the west of the Hooghly, and the River Rasulpur, with a comparatively small drainage-area, flowing into the wide Hooghly estuary where the tidal rise is large, can have no appreciable influence on the channels in the estuary.

Alluvium carried down the Hooghly.—From some observations made in 1893 by Mr. C. G. Livesay, on the proportion of alluvium contained in the waters of the upper part of the Bhagirathi in flood-time, at different periods and at different depths,[1] the Author has estimated [2] the average total volume of solid matter discharged annually by the Hooghly to amount to about 90 million cubic yards, which, with a yearly fresh-water discharge reckoned to average about 220,000 million cubic yards, is a ratio of alluvium to fresh-water flow of 1 in 2,444. This is nearly identical with the ratio of 1 in 2,420 calculated from observations in the case of the Mississippi, somewhat less than 1 in 2,166 obtained for the Rhone, but considerably larger than the estimated ratio of alluvium to discharge in the Danube and the Volga.

The very fine silt, which constitutes a considerable portion of the alluvium derived from the Ganges, is the most conspicuous feature in the waters of the Hooghly, for it is very readily carried down in suspension by the freshets, and stirred up or kept in suspension by the tidal currents. It is, however, the sandy part of the alluvium which, settling readily in proportion to its coarseness as the descending current slackens on the abatement of the freshets, forms the shoals and bars which are impediments to navigation and a danger to shipping; whereas the muddy silt, which renders the waters of the Hooghly so turbid, even during

[1] J. H. Apjohn, "Navigation Canals in India," pp. 15 and 16. Calcutta, 1895.

[2] L. F. Vernon-Harcourt, "Report on the River Húgli," pp. 5–9. Calcutta, 1897.

the dry season when no alluvium is being brought into the river from above, only settles in recesses and sheltered places beyond the influences of the currents, or is gradually dispersed on reaching the sea, by the tidal ebb and flow and by waves.

Tidal Flow.—The tidal influence at high spring-tides extends up the Hooghly about 5 miles above Nadia (Fig. 1, Plate 2), or about 181 miles above its mouth and 84 miles above Calcutta, during the latter half of the dry season, and ceases about 40 miles lower down, or 141 miles above its mouth, at the height of the freshets. The mean tidal range at the height of ordinary spring-tides, which is 11 feet in the Bay of Bengal in front of the approach channel to the Hooghly, gradually increases as the tidal flow converges in approaching the narrowing estuary and passing up to the contracted channel of the river, reaching 14 feet 2½ inches at the entrance to the estuary, and attaining 15 feet 9½ inches at Diamond Harbour: but owing to the gradual rise of the low-water line above Hooghly Point, the tidal range decreases on going higher up the river, so that it only averages 11 feet 8½ inches at Kidderpur, 3 miles below Calcutta, at the height of ordinary spring-tides (Figs. 3–6, Plate 2).

Tidal Currents.—There are three different tidal conditions of the Hooghly, each lasting about 4 months. During the first period, in the cold season on the abatement of the freshets, the currents in the river are at their minimum strength, and the flood-tide current is somewhat stronger than that of the ebb, owing to its shorter duration by about 2 hours. During the latter half of the dry season, the flood-tide, being impelled up the river by the south-west monsoon, has a considerable preponderance over the ebb-tide, till it is checked by the descent of the freshets. On the other hand, during the rainy season, the flood-tide is overpowered by the downward current of the freshets in the river above its estuary, so that in ascending the river the tidal rise becomes more and more a mere backing up of the fresh water, till, on reaching Calcutta, the effect of the flood-tide is generally only a checking of the downward flow.

Tidal Condition.—The tidal diagrams, giving the records of the tide gauges established at different stations along the river (Figs. 3 and 5), and, more particularly, the simultaneous tidal lines obtained from the tidal observations (Figs. 4 and 6), exhibit clearly the tidal condition of the river in the dry and rainy seasons respectively. The tides selected for illustration are one of the highest spring-tides of the latter half of the dry season, and one of the highest spring-tides during the height of the freshets, thereby indicating the most marked tidal influences, and the greatest possible contrast of tidal conditions.

The tidal diagram and simultaneous tidal lines of the high spring-tide of the 30th March, 1896, indicate best the tidal condition of the Hooghly; for, at that period of the year, the tidal influx is practically unaffected by the fresh-water discharge (Figs. 3 and 4, Plate 2). The diagrams show that the tidal condition of the estuary is fairly satisfactory; for the tide rose 9 inches higher at Balari than at Khijiri, which may be attributed to the trumpet-shaped form of the estuary; and the tidal range was 4½ inches greater at the upper station. There was a fall of 5 inches in the high-water line between Balari and Hooghly Point, which was nearly compensated for by a depression of 4 inches in the low-water line. A deterioration, however, of the tidal condition becomes clearly manifest on passing up from Hooghly Point to Moyapur, in the steepening of the crest of the advancing flood-tide, and a slight fall of the high-water line, both of which unfavourable appearances become intensified during the progression of the flood-tide up to Buj-Buj, where the crest of the incoming flood-tide assumes the form of a bore, which attained a height of slightly over 4 feet on the 30th March, 1896; whilst the fall of the high-water line was 6 inches. Moreover, though the high-water line rises again in proceeding to Kidderpur, high-water having been 9 inches higher there than at Buj-Buj, and only 3 inches lower than at Balari on that particular tide, so that the reduction in range at Kidderpur is due to the rise of the low-water line inland, the bore maintained the same height from Buj-Buj to Kidderpur, increased slightly in height on ascending to Konnagar, and reached a maximum of 5 feet 4½ inches at Chinsurah, appearing as a travelling wave with a considerable subsequent temporary depression (Fig. 3). The bore then diminishes considerably in height, with the reduction in tidal range, on passing up to Noaserai, and dies out before the flood-tide reaches Nadia. The high-water line, however, falls between Kidderpur and Nadia to the extent of 2 feet 3 inches at a high spring-tide, reducing the tidal range at Nadia to 2 feet, and thereby involving a considerable loss of tidal volume and scour in the upper part of the river. The bore, and the fall in the high-water line up the river, are due to the obstructions offered to the influx of the flood-tide, in the dry season, by the sandbanks in the channel and the bends of the river.

Though the tidal conditions are considerably altered by the descent of the freshets in the rainy season—arresting, as they do, the influx of tidal water into the river above its estuary, and materially reducing the distance up the river to which tidal influences extend—nevertheless, in the estuary, and even to a certain extent as far up as Kidderpur, the modification consists rather in the raising of the low-water line by the large fresh-water discharge, and in the raising of the high-water line by the backing up of the flood-waters, especially above the estuary, than in any marked reduction in the tidal range: as is clearly indicated by a comparison of the tidal diagram and simultaneous tidal lines of the high spring-tide of the 12th August, 1889 (Figs. 5 and 6, Plate 2), and those of the 30th March, 1896 (Figs. 3 and 4, Plate 2). Contrasting these two tides, the low-water line of the flood-season is 1 foot 7 inches higher at Khijiri, 1 foot 10 inches at Balari, 2 feet 1 inch at Hooghly Point, 3 feet 7 inches at Moyapur, and 5 feet 6 inches higher at Kidderpur, than that of the dry season; whilst the reduction in range of the spring-tide during the height of the freshets, as compared with that of the dry season, is only 9 inches at Khijiri, 3 inches at Balari and Hooghly Point, 1 foot 3 inches at Moyapur, and 1 foot 8 inches at Kidderpur.

Tidal Flow into the Hooghly.—At a high spring-tide during the latter half of the dry season, when it is high water at Khijiri it is low water at Kidderpur; and the tide has fallen to low water at Hooghly Point before high water is reached at Nadia, 11 hours after high water at the mouth of the estuary, the distance up to Nadia being about 176 miles. At a high spring-tide during the freshets, high water at Balari nearly corresponds with low water at Kidderpur; and high water occurs at Dumardaha about 6 hours after high water at the mouth, a distance of about 133 miles. Owing to the great width at the mouth, and the large area and length of the Hooghly estuary, the influx of tidal water at a high spring-tide in the dry season has been calculated to amount, during the 5½ hours of flood-tide, to a little over four-and-a-half times the maximum fresh-water discharge at the height of the freshets; but the tidal influx is greatly reduced in passing up the comparatively narrow river, so that the flow past Calcutta on such a tide has been reckoned at about one-fourth only of the maximum fresh-water discharge. Even during the freshets, notwithstanding the large volume of fresh water coming down, the influx of tidal water at a high spring-tide into the estuary reaches nearly four times the maximum fresh-water discharge; but the influx decreases rapidly in proceeding up the estuary, so that on reaching Hooghly Point, the tidal rise, when all the tributaries are in high flood, consists merely in a backing up of the large fresh-water discharge by the rise of tide in the estuary. Moreover, the descent of the freshets is not arrested at Kidderpur, even at high water of a high spring-tide, for the increased volume in the river above Kidderpur, resulting from the raising of the water-level during the 3 hours of flood-tide, is less than half the maximum fresh-water discharge during this period.

Influences of Fresh-water Discharge, and of Tidal Flow, on the River.—The existence of the Hooghly, like that of all other rivers, is due to its fresh-water discharge; but Mr. Longridge, in comparing the Hooghly with the Mutla, in the Paper already referred to, attributed the defects in the navigable condition of the Hooghly to its fresh-water discharge, on account of the large quantity of alluvium carried down by its floods, to which the formation of sandbanks and shoals in the river and its estuary are due.[1] No doubt a river discharging perfectly clear water, or an arm of the sea into which the flood-tide brings no alluvium, would offer fewer obstructions to navigation than a branch of a deltaic river; but the fresh-water discharge of the Hooghly, besides being the source to which the river owes its existence and its tidal capacity, during the freshets scours out the river, which would otherwise be silted up gradually by the sediment brought in by the predominant flood-tide during the dry season.

Whilst the fresh-water discharge increases the navigable depth in the Hooghly during the rainy season, by scouring out the ebb-tide channel and raising the water-level, it becomes so small during the dry season, that the tidal influx has to provide the navigable depth over the shoals at high tide for two-thirds of the year. In fact, the Hooghly, in the absence of any tidal flow, would be in a much worse condition than some other deltaic rivers; for its minimum discharge past Calcutta, throughout the dry season, hardly attains one-thirteenth of its maximum discharge, and is smaller in proportion lower down; whereas the proportion of minimum to maximum discharge is one-eighth in the case of the Danube, and only one-fourth for the Mississippi. Moreover, the tidal influx and efflux, combined with the wide outlet which they have formed, produce a dispersion of the alluvium brought down from the interior over a very extensive area, and prevent the heavier sediment in suspension from being deposited in slack water, and forming a bar right in front of the mouth of the river. Thus, whereas the original depth over the

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 21.

bar in front of the mouth of the South Pass of the Mississippi delta was 8 feet, and in front of the Sulina mouth of the Danube delta was 8 feet, the navigable channel through the wide outlet of the Hooghly estuary has maintained a minimum depth of 15 feet at the lowest low-water of the dry season, which provides an available depth of 29 feet at high water of ordinary spring-tides.

Channels and their Changes in the River Hooghly.

Divergence of the Flood- and Ebb-tide Channels.—On the low-water charts of large estuaries and wide reaches of winding tidal rivers, blind channels may generally be observed, which can be traced to the action of the flood-tide running up in a direction different from the course of the navigable ebb-tide channel. As instances of these blind flood-tide channels in estuaries, may be cited: the Great Nore to the south of the Nore Light near the mouth of the Thames; the channel at the back of Foul Holme Sand on the north side of the Humber estuary; the Sloyne on the Cheshire side of the Upper Mersey estuary; the Bog Hole, opposite Southport, on the south side of the Ribble estuary; a channel running past Cardross on the northern side of the Clyde estuary; a channel at the back of the old Seal Bank in the Garvogue estuary leading up to Sligo; and a blind channel running part of the way up the Seine estuary, on the north or south side according as the navigable channel is on the south or north side. Illustrations of blind flood-tide channels in winding rivers are furnished by the River Seine above its estuary before the training-works were carried out, and by the River Usk, in which there are three very clear examples of these channels below Newport, one to the east of the navigable channel near the mouth of the river opposite the Usk Lighthouse, another near the left bank in front of the Eastern Dry Docks to above the lower entrance of the Alexandra Docks, and the third along the right bank from opposite Latch's Wharf to a short distance above Gwenlly Pill. In these cases the main flood-tide current, coming up the river, follows as straight a course as practicable; whereas the main ebb-tide current, following the ordinary downward course of flow of a non-tidal river, runs close alongside the concave banks in the bends, crossing over as usual in the interval between two bends to the opposite bank of the river.

The influence of the flood-tide in forming channels diverging from the ebb-tide channels, is naturally greatest during the low stage of a river, when the fresh-water discharge is at a minimum, leaving more space in the river for the influx of the flood-tide. Accordingly, the divergence of the channels under the influence of the two distinct forces of flood- and ebb-tides, and the consequent changes in the channels according to the seasons, are particularly clearly marked in a river like the Hooghly, where the fresh-water discharge is so great during the rainy season, and the flood-tide has such a decided predominance during the rest of the year. Some distinct flood-tide channels may be noticed in the charts, approaching or running up the Hooghly estuary, namely, the Eastern Channel, the Gaspar Channel, the deep Saugor Roads and Bedford Channel, and the Western Channel and Kaukhali Roads (Fig. 2, Plate 2, and Fig. 7, Plate 3).

Above the estuary the effect of the flood-tide is clearly visible in the blind low-water channels cutting into the sandbanks projecting from the convex bank at the various bends, commencing with Diamond Sand, and also specially evident at Brul Sand, Royapur Sand (Figs. 14, 15, and 16, Plate 4), Buj-Buj Sand, Koffri Sand, and Munikholi Sand (Fig. 2, Plate 2, and Fig. 7, Plate 3). The energy of the incoming flood-tide is thus, to some extent, spent in fruitless efforts to form a channel through these sandbanks stretching in front of its direct course, till at length, in rising, it eventually takes the line of least resistance along the ebb-tide channel following the opposite concave bank. If this were the only result of the absence of coincidence in the action of the flood- and ebb-tides, there would merely be a certain loss of tidal scour at places where the concave bank ensures an ample depth in the navigable ebb-tide channel. These sandbanks, however, in conjunction with the frequent and considerable changes in direction necessitated by the sinuosities of the river, check the upward progress of the flood-tide throughout the dry season, and by thus reducing the tidal volume passing up, diminish the power of the resulting ebb. A much more serious result, moreover, is liable to occur at the crossings between the bends, by the divergent courses of the flood- and ebb-tides at these places under certain conditions, and especially where these reaches have been gradually widened by the scour of the currents. Even in non-tidal rivers, the navigable channel is shallower in crossing over from one bank to the opposite one between two bends of a winding river; and the river requires reduction in width at such places, to provide against undue shoaling by increasing the scour of the current. This reduction in depth between two bends is naturally intensified in the case of a tidal river where a strong flood-tide runs up close to one bank of the river above a bend, whilst the ebb-tide hugs the opposite bank before crossing over to the bend below, which is exemplified by the Hooghly at certain places during the predominance of the flood-tide in the dry season. The formation of a deep channel on each side of the river in the reach between two bends occurs when the configuration of the bank above a concave bend causes the flood-tide, in pursuing as straight a course as possible, to keep alongside this bank considerably above the place where the ebb-tide crosses over from the deep channel it has formed along the opposite bank, to flow round the concave bank below, leaving a central shoal between the deep flood- and ebb-tide channels. Any widening of the reach between the bends promotes the development of the central shoal, by increasing the divergence of the channels; whereas a narrow reach, with a configuration of the bank above the concave bend tending to divert the flood- or ebb-tide more directly towards the opposite bank, leads to the coalescing of the flood- and ebb-tide channels, resulting in a fair depth being maintained over the crossing. Thus, in proceeding down the Hooghly from Calcutta, there are only two adjacent, sharp, reverse bends down to Atchipur Point, opposite Ulabaria, namely, round Sankral and Munikholi Sands, where the configuration of the banks produces a confluence of the flood- and ebb-tide channels at the crossings, as well as round the bends; and the conditions are sufficiently favourable at the crossings between the other moderate bends for a 3-fathom channel to be maintained continuously, below the lowest low-water, down nearly to Hiragunj Point, and with only three short breaks in the 5-fathom channel, namely, above Kidderpur, and at the crossings a little above Hangman's Point and Pir Serang (Fig. 7).

Below Atchipur Point there are three reaches where the 3-fathom channel is interrupted by a shoal at the crossing, owing to the divergence of the channels formed by the flood and the ebb on opposite banks of the river. These reaches are Moyapur Reach between Atchipur Point and Hiragunj Point, Royapur Reach between Hiragunj Point and Brul Point, and the James and Mary Reach between Fulta Point and Hooghly Point, so called in consequence of the wreck of "The Royall James and Mary" on the central shoal known now as the Muckraputty Sand, on the 24th September, 1694.[1]

[1] Colonel Henry Yule, "The Diary of William Hedges during his Agency in Bengal." London (Printed for the Hakluyt Society) 1887–9. vol. ii. (1888),

Moyapur Crossing.—At the bend at Ulabaria, and along the concave bank below, the channel of the freshets and ebb-tide keeps close to the right bank of the river till, in changing its curvature rather more than half-way to Hiragunj Point, it begins to leave the right bank on its way to the concave left bank in the bend just above Royapur. On the contrary, the flood-tide channel of the dry season passing up, in front of Royapur, the deep, joint channel of both tides, keeps alongside the concave left bank above the bend, till after passing the Moyapur magazine, it becomes shoaler and gradually disappears, owing to the left bank becoming convex, and on account of the impediment offered to the progress of the flood-tide by the sands projecting down-stream from the Atchipur Flat along the left bank (Figs. 14, 15, and 16, Plate 4). Accordingly, the deep flood-tide channel along the left bank overlaps the deep ebb-tide channel along the right bank, leaving a shoal between them. There was, indeed, a continuous 3-fathom channel along the Moyapur crossing in 1883 (Fig. 14); but there was a break in the 3-fathom channel at the crossing in January, 1896 (Fig. 15), which is shown decidedly larger in the survey of January, 1900, the deep ebb-tide channel along the right bank being distinctly shorter than in 1896, and the sandbank projecting from Hiragunj Point exhibiting a considerable increase in size (Fig. 16).

The deterioration of the navigable condition of this crossing may be traced to the gradual widening of this reach, near the crossing, by 100 feet to 200 feet between 1883 and 1900, so that now it is 870 feet wider near the crossing than at Atchipur Point, and only 300 feet less in width than in the wide bend below, with its extensive sandbank opposite Hiragunj Point.

Royapur Crossing.—The conditions are precisely similar at the crossing in the Royapur reach below Hiragunj Point, though, owing to the reversal of the curvature, the ebb-tide channel hugs the left bank till it approaches Brul Sand, and the flood-tide channel runs up alongside the right bank; whilst the influence of the direct course of the flood-tide current is shown by the way in which it cuts into the Royapur Sand at the upper end of the reach (Fig. 16, Plate 4). In spite, however, of the divergence of the main flood- and ebb-tide channels along opposite banks, a

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"III. Notices of various persons mentioned in the diary of Hedges," "Eyres," p. 133; "Master," p. 233: vol. iii. (1889), "VII. Early Charts and Topography of the Húgli River," pp. 197, 204, and 210, and chart of river opposite p. 220, probably of about 1703.

continuous 3-fathom channel is shown on the surveys of 1883 and 1896 (Figs. 14 and 15, Plate 4). The survey of December, 1901, exhibits a break in the 3-fathom depth, with a shoal between the deep flood- and ebb-tide channels along either bank, giving an available depth over the crossing of only about 13 feet at the lowest low-water, equivalent to a shoaling of 4 feet or 5 feet since 1883, after making allowance for the more unfavourable period as regards depth of the last survey. The deterioration in this case, like that at the Moyapur crossing, must be attributed to the increase in the width of the Royapur reach near the crossing, amounting to 150 to 250 feet between 1883 and 1901, being a larger erosion by about 50 feet than at Moyapur during a period rather less than 2 years longer. The decrease in depth is a natural consequence of the increase in width, which leads to a greater divergence between the flood- and ebb-tide channels running along opposite banks of the river, where a reduction in width, or the guidance of one of the tidal currents across the river into the channel of the other, is needed to lower the shoal at the crossing.

Crossings between Brul Sand and the James and Mary Shoal.— Another crossing naturally occurs between the bend round Brul Sand and the bend on the opposite side of the river in front of Dhaja Point; but owing to the configuration of the concave right bank of the river in front of Brul Sand and on to Pukuria Point, the ebb-tide current, after passing round the bend, is directed diagonally across the river into the flood-tide channel coming up along the opposite left bank (Figs. 14, 15, and 16). Consequently, the freshets and ebb-tide provide a fixed, stable channel over the crossing with an available depth of not less than 5 fathoms, into which the flood-tide current is mainly drawn, though still partly following its normal straight course, as shown by the erosion it produces into the lower face of the Brul Sand.

On reaching Fulta Point, where the concavity of the left bank in the bend round Dhaja Point terminates, the conditions are peculiar; for owing to the configuration of the left bank just above Fulta Point, the ebb-tide current should, under normal circumstances, pass across the river, and eroding the Damuda Flat, form a deep channel along the concave right bank down to near Shipgunj Point, where it might have been expected to cross over again to the left bank (Fig. 2, Plate 2, and Figs. 14, 15, and 16, Plate 4). The exceptional position of the deep channel alongside a point, and keeping generally close to the same bank beyond the point, instead of crossing over as usual, appears to be due mainly to the outflow from the River Damuda, and the deposit of sand where the discharge of the Damuda meets the discharge of the Hooghly at right angles; and the consequent diversion of the descending current, and its maintenance near the left bank, is facilitated during the dry season by the predominant flood-tide current, coming up along the right bank, being directed across the river to the left bank above Ninan on passing Shipgunj Point.

The James and Mary Shoal.—The portion of the Hooghly from Fulta Point down to a point abreast of Hooghly Point is known as the James and Mary reach; and the James and Mary shoal, including the Muckraputty sandbank, occupies the lower end of the reach, the shoal during the dry season joining the Hooghly Sand just below Hooghly Point, and stretching some distance up the centre of the reach, with the deep channels of the Eastern and Western Guts on each side of it, running alongside the left and right banks of the river respectively (Figs. 11–16, Plate 4). The river makes a great bend, somewhat sharper than a right angle, round Hooghly Point; and the River Rupnarayan flows in on the right bank in the outer circle of the bend, in a direction approximately coinciding with the course of the Hooghly below the bend. The Rupnarayan, which receives a considerable portion of the overflow of the floods of the Damuda, may be regarded as the cause of this abrupt diversion of the course of the Hooghly; but though this river, when discharging a high flood towards the close of the freshets, may promote the deposition of sand in the reach just above its confluence, by checking the current of the Hooghly, the existence of the James and Mary shoal appears to be really due to the divergence of the flood- and ebb-tide currents. The descending current of the freshets, in the rainy season, scours out a deep channel alongside the concave left bank, and diverging only slightly from this bank on passing Nurpur Point, it goes straight across the river into the very deep channel along the concave right bank below the bend, a little beyond Gewankhali; whilst the deep flood-tide channel along the right bank, from Mornington Point towards Shipgunj Point, becomes more or less silted up during the prevalence of the freshets. On the other hand, during the dry season the flood-tide channel, or Western Gut, along the right bank, in the lower part of the reach, opens out again, till the scouring energy of the flood-tide current is dissipated to some extent on approaching Shipgunj Point, where it spreads out and passes across to the left bank between Ninan and Fulta Point. At the same time, the Eastern Gut near the left bank, which depends on the ebb-tide almost entirely for its maintenance throughout the dry season, is reduced in depth; and a bar is formed between the ebb-tide channel near Hooghly Point and the deep channel at right angles to it in front of Gewankhali, by the conflicting action of the flood-tide running up this latter channel, thereby joining the James and Mary shoal to the Hooghly Sand below (Figs. 11 and 13–16, Plate 4). The James and Mary shoal has therefore been naturally formed in the central slack water of an unduly wide reach, in which the descending and ascending currents run along opposite banks; and this shoal is extended across the Eastern Gut during the dry season by the predominant flood-tide flowing up at right angles to the enfeebled ebb-tide, especially during the prevalence of the south-west monsoon between March and July. The Eastern Gut has generally its greatest available depth over the bar at its southern extremity, where the navigable track crosses the river, towards the close of the freshets in October and November, and its least depth between May and July. The channel along the Western Gut, where it crosses the river opposite Shipgunj Point, is usually deepest between April and June, and shallowest in October and November.

The width of the Hooghly in the James and Mary reach has been gradually increasing; for in the 20 years 1875–95 the river was enlarged about 150 feet opposite Fulta Point, 440 feet about half-way between Fulta Point and Shipgunj Point, about 50 feet at this last point, 190 feet a little farther down, and about 200 feet opposite Hope's Obelisk. According to the last survey, however, taken in December, 1901, some accretion appears to have taken place since 1895 along the right bank, which has, for a time at any rate, reduced this enlargement by about 50 feet to 100 feet; but, on the other hand, the widening had evidently been in progress long before 1875, as may be readily seen by comparing the surveys of 1813–14 and 1836 with the survey of 1875 (Figs. 11, 12, and 13). An examination of the several surveys on Plate 4, shows how the gradual widening of the reach has been accompanied by the gradual rising and extension of the James and Mary shoal, the emergence and growth of the Muckraputty sandbank in the centre of the lower part of the reach, and the progressive deterioration of the Western Gut, owing to its being farther removed from the influence of the ebb-tide current by the widening of the river and the extension of the central sandbank (Figs. 11–16). The growth of the central sandbank checks the influx of the flood-

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tide, as is shown by the cut made into the lower end of both the central shoal and the sandbank in the later charts, by a minor branch of the flood-tide endeavouring to form a passage up the centre of the reach, and also by the deep flood-tide channel along the right bank, which in the survey of 1813–14 extended over 2 miles above Mornington Point at the entrance to the River Rupnarayan, and $1\frac{3}{4}$ mile in the survey of 1836, having been restricted to $1\frac{1}{2}$ mile in the more recent surveys.

The James and Mary shoal is recognized as the most dangerous place for navigation on the river, on account of the shifting character of the sands, the great and rapid variations which are liable to occur in the depth over the bar across the lower end of the Eastern Gut, owing to the great divergence of the flood- and ebb-tide currents during the dry season, and the cross currents to which vessels are exposed at certain states of the tide in passing round the bend opposite Hooghly Point.

Ninan Bar in the James and Mary Reach.—When the deep channel passing close to Fulta Point assumes a central course below, a bar is formed, in the neighbourhood of Lower Ninan, between this channel and the deep channel which always exists near the left bank, extending from Lower Ninan down to Hooghly Point. It is clearly shown in the survey of 1836, and there is some approach to it in the surveys of 1875 and 1895, owing to the existence of a central branch channel (Figs. 12, 13, and 15, Plate 4). The position of this deep channel varies with the relative influences of the discharges from the Hooghly and the Damuda, to which combination it owes its existence alongside the projecting point. When a fair portion of the descending current of the Hooghly passes close to Dhaja Flat, as indicated by the existence of a channel between Fulta Sand and the right bank, which appears in the survey of 1882–83 (Fig. 14), this portion of the current assists the discharge from the Damuda in directing the main current, and consequently the deep channel, to the concave left bank above Ninan; and therefore the deep channel, under these conditions, pursues an unbroken course along the left bank down to Hooghly Point. On the contrary, when Fulta Sand is extended so as to join Dhaja Flat, obliterating the branch channel along the right bank, the main downward current of the Hooghly is concentrated against the concave left bank above Fulta Point, and would, consequently, scour out a deep channel in a central course below Fulta Point, unless adequately counteracted by the discharge from the Damuda. Accordingly, the influence of the discharge of the Damuda in relation to the discharge of the Hooghly becomes the governing factor in determining the position of the deep channel below Fulta Point. On account, however, of the diversion of a considerable portion of the flood-overflow of the Damuda into the Rupnarayan during high floods, the ratio borne by the discharge of the Damuda from its outlet to the discharge of the Hooghly—and therefore the influence of the Damuda in pushing the deep channel towards the left bank below Fulta Point—varies inversely with the rainfall in the rainy season; for, during high floods the discharge of the Hooghly is proportionately large, whereas the Damuda loses a large portion of its flood-discharge before reaching its outlet. When, on the contrary, a small rainfall causes the floods of these rivers to be moderate, the loss of water from the Damuda is small, and the discharge of the Damuda through its outlet is much larger in proportion to the discharge of the Hooghly than when a large rainfall produces high floods.

Channel from opposite Hooghly Point to the Estuary.—After passing over the bar of the James and Mary shoal across the southern end of the Eastern Gut, a very deep channel appears in all the surveys close along the right bank of the Hooghly from near Gewankhali down to beyond Luff Point, forming a continuation in the dry season of the deep Western Gut (Fig. 2, Plate 2; Fig. 7, Plate 3; and Plate 4). The rapid currents of the freshets of the Hooghly and the Rupnarayan in the rainy season, and of the flood-tide in the dry season, which maintains this deep channel, produce erosion of the concave right bank near Gewankhali, which has averaged at least 8½ feet yearly since 1875. The Hooghly is therefore being continuously widened in front of Hooghly Point, which will gradually promote the enlargement of the James and Mary shoal opposite that Point, and will tend to draw the deep channel farther away from the southern end of the Eastern Gut, thereby increasing the width of the shoal at the crossing during the dry season. The projection of Luff Point directs the navigable channel across the river to the left bank near Hospital Point, whence it continues along the concave curve of this bank, constituting Diamond Harbour, down to Kantabaria. Though the depth of the channel is naturally somewhat reduced at the crossing, the good course given by Luff Point to the freshets and ebb-tide, assisted by the Kukrahati shoal, which is formed under the shelter of the Point as the freshets abate, causes the descending current and flood-tide to follow the same direction, so that a depth of more than 5 fathoms is generally maintained throughout; and the portion of the river between Hooghly Point and Kantabaria is in an excellent, stable condition with an ample depth. Moreover, the deep 5-fathom channel extends past Kantabaria into the estuary beyond Kulpi, and nearly as far as opposite Rangafala Island.

Limitations in the Indications of the Surveys.—Above its estuary the Hooghly is constantly undergoing seasonal changes, particularly when the arrival of the freshets causes the descending current to scour out the ebb-tide channel and silt up the flood-tide blind channels ; again, when the freshets, on subsiding, begin to deposit some of the sediment, with which they are charged, in the main channel as well as at the sides; and, lastly, when the flood-tide obtains the predominance, opening out again the flood-tide channels where they diverge from the ebb-tide channel, and, in its turn, shoaling up this channel in certain places where its current diverges from the course of the ebb-tide, especially in the latter part of the dry season, when it attains its greatest force. The relative permanence of the ebb-tide channel, as compared with the flood-tide channels, is due both to the scour it undergoes during the freshets, and the continuous, though comparatively feeble action, of the ebb-tide throughout the dry season, as well as the more regular continuity of the ebb-tide channel, as compared with that formed by the flood-tide, in consequence of which the ebb-tide channel is generally the course followed by vessels, in spite of the predominating influence of the flood-tide during two-thirds of the year.

All the surveys of the river are made during the dry season, so that no indications are given in them of the condition of the main channel and sandbanks during the freshets; and the relative states of the flood-tide and ebb-tide channels, and the positions and depths at the crossings, vary according as the surveys are made early or late in the dry season. If surveys could be made during the freshets, they would doubtless show a deep ebb-tide channel throughout at the height of the freshets, the blind flood-tide channels silted up, and the sandbanks projecting from the convex banks reduced in extent. Towards the close of the freshets, as soon as the velocity of the silt-bearing current has been considerably reduced, the ebb-tide channel would present a diminished depth, and the sandbanks and shoals would be increased again in area; but the condition shown upon the surveys, some of which have been reproduced in Plates 2–4, would not be re-established till the flood-tide had begun again to scour out its blind channels, which had been obliterated by the freshets. There are, accordingly, three distinct states of the river above its estuary, which gradually change from one to the next, according to the seasonal influences: first, the state at the height of the freshets; then the state when the freshets abate; and, lastly, the state which is reached in the dry season, and is alone recorded in the surveys, varying somewhat with the month in which the survey has been taken.

Channels and Changes in the Hooghly Estuary.

On emerging from the narrow neck opposite Kantabaria, the Hooghly expands into an estuary which exhibits the special features of a tidal estuary, comprising shifting channels, shoals, and sandbanks. The estuary is broken up by a series of deep channels separated by shoals, without any very clearly defined principal navigable channel, from which the course best combining fair stability, depth, and shelter, is selected from time to time, and buoyed (Fig. 2, Plate 2, and Fig. 7, Plate 3).

Variations in the Route of the Navigable Channel.—The chief routes which have been followed by the navigable channels through the Hooghly estuary at different dates, as gathered from the principal charts since 1768–70, are shown in Fig. 10, Plate 3; and, as usual in sandy tidal estuaries, they range over a considerable portion of the estuary. The differences in route indicated on the Figure do not in the least imply that the former navigable channel has entirely shifted its position to the extent shown by the different lines; for what is termed the navigable channel is merely the most suitable course buoyed through a succession of deep channels separated by shoals, the raising of one of which, owing to changes in the sands of the estuary, may necessitate shifting the course into a different set of deep channels to obtain a deeper channel over the intervening shoals than the old course can provide, owing possibly to a moderate reduction in depth at one spot. Thus the opening out of the Gabtola Channel, leading from the Jellingham Channel into the Bedford Channel, of which there were signs in the chart of 1895–96, though barred at that time by a narrow high shoal at its lower end, and the simultaneous shoaling of the upper end of the Eden Channel, occasioned the change of course of the navigable channel in 1897–98 as clearly shown on the chart of 1902 (Figs. 7 and 10).

Channels and Bars in the Estuary.—To facilitate reference, all the various long pools of more than 3 fathoms in depth at the lowest low-water in the Hooghly estuary, known as channels, of which there are three rows opposite Saugor Island, have been given distinctive names, which are printed on the several charts, and which also serve to distinguish the buoys marking the navigable channel (Fig. 7, Plate 3).

The consecutive, long, deep pools, or channels, providing the route for navigation through the estuary, are generally separated from one another by shoals or bars, having a depth over them of less than 3 fathoms at the lowest low-water, which vary considerably in width from year to year, and, to some extent, in position. In the earlier charts, the Inner Rangafala Channel alongside the left bank, or the Outer Rangafala Channel in the centre of the upper estuary, from Kulpi to opposite the upper end of Saugor Island, was used for the navigable channel. At some period between 1864 and 1882, however, the Balari Channel alongside the right bank, having gradually opened as the Inner Rangafala Channel closed, was selected as the navigable channel in preference to the Outer Rangafala Channel, as shown on the chart of 1867–82, on account of its greater stability and less exposure; though for many years subsequently the Outer Rangafala Channel had a much less width of bar than the Balari Channel, and it is also more direct, as clearly indicated on the chart of 1888 (Fig. 2, Plate 2). Since 1888, however, the Rangafala Channel has deteriorated considerably, so that now it is narrow near the Outer Rangafala Sand, and is separated at its lower end from the Jellingham Channel by a bar which, though somewhat narrow, has an available depth over it of only 7 to 8 feet at the lowest low-water; and, accordingly, the Balari Channel has now become the deepest channel, as well as the most stable and best sheltered (Fig. 7, Plate 3). Reckoning as bars shoals with a less depth than 3 fathoms over them at the lowest low-water, a bar has always existed along the upper part of the Balari Channel, and sometimes another lower down; and a bar has generally been found between the Haldia Channel and the Jellingham Channel, and between the latter and the Dredge Channel, and almost always along part of the Eden Channel, and across the Middleton shoal between Saugor Roads and the Gaspar Channel. In the six complete charts issued between 1883–84 and 1895–96, with the exception of a very favourable condition exhibited by the chart of 1889–90, when the only bar was near Balari, 1 mile in width, the total length of the bars along the navigable channel ranged between $7\frac{3}{10}$ miles in 1895–96 and $10\frac{3}{4}$ miles in 1894–95, and averaged $8\frac{3}{4}$ miles in the three earlier charts, and $8\frac{1}{2}$ miles in the three later charts. In the chart of 1888, selected for illustration as being the earliest of the new set of charts of the estuary which was carried out to the Gaspar Channel, only two bars appear across the navigable channel, namely, at Balari and in the Eden Channel, the former being $6\frac{1}{4}$ miles in length, and the latter $4\frac{1}{4}$ miles along the centre of the buoyed channel (Fig. 2, Plate 2).

In the chart of the estuary of 1897–98, the Gabtola Channel leading from the Jellingham Channel into the Bedford Channel, and thereby superseding the Dredge and Eden Channels, appears for the first time as the buoyed navigable channel. In this chart there is an upper and a lower bar in the Balari Channel, with lengths along the navigable channel of 1,000 feet and 3,500 feet respectively, a bar between the Haldia and Jellingham Channels 4,000 feet across, a bar 1,000 feet long at the lower end of the Gabtola Channel where it joins the Bedford Channel, and a bar 3,000 feet in length across the Middleton Sand between Saugor Roads and the Gaspar Channel, making in all about $2\frac{1}{3}$ miles of shoals across the navigable channel with a depth of less than 3 fathoms over them at the lowest low-water. This was a great reduction in the length of the bars when compared with the $7\frac{3}{10}$ miles of the previous chart of 1895–96, or the $10\frac{1}{2}$ miles of 1888, owing largely to the change of route. The latest chart, 1902, shows the upper Balari bar increased in length to 6,500 feet, the lower bar 9,000 feet long as in the chart of 1900–1901, the Gabtola bar reduced from 6,500 feet in 1900–1901 to 1,700 feet, and the Gaspar bar across the spit reduced to 1,000 feet (Fig. 7, Plate 3), thereby making the total length of shoals across the navigable channel a little less than $3\frac{1}{2}$ miles, being a reduction of about $\frac{2}{5}$ mile from their length in the previous chart. The minimum available depth at the lowest low-water across the bars in the navigable channel through the estuary, which was 11 feet over the Jellingham-Dredge bar in the chart of 1895–96, was 14 feet over the Gabtola bar in 1897–98, 13 feet over the Gabtola bar in 1899–1900, 15 feet over both Balari bars in 1900–1901, and also again in the latest chart of 1902.

Changes in the Estuary.—The upper part of the estuary is necessarily most influenced by the freshets, whose power is gradually reduced in descending the estuary by mingling with the rapidly increasing mass of tidal water coming in through the wide outlet, even during the rainy season. It is therefore in the upper estuary, from Kulpi down to the northern part of Saugor Island, that changes might be traced to the freshets, and would have the most permanence.

The shifting of the main navigable channel from the Inner

Rangafala Channel, running between Rangafala Island and the left bank past Middle Point, to the Outer Rangafala Channel between 1836 and 1854, and the recently acquired superiority of the Balari Channel over the Outer Rangafala Channel, as clearly indicated by comparison of the charts of 1888 and 1902 (Fig. 2, Plate 2, and Fig. 7, Plate 3), are doubtless due to the somewhat westward change in direction imparted to the freshets and ebb-tide, in issuing from the narrow neck at Kantabaria, by the junction of the Diamond Sand with the right bank subsequently to 1864, the gradual extension of this sandbank into the channel, and the consequent erosion of the concave left bank above Kantabaria. This last gradual shifting of the deepest channel from the centre to the right bank, from the upper end of the estuary down to Haldia Point, has evidently led, ever since 1888, to the obliteration of the remains of the Inner Rangafala Channel, a large extension of the Rangafala Islands and the adjacent sandbanks from Kulpi to Silver Tree, a notable shoaling of the entrance to Channel Creek near Mud Point, the formation of the adjacent Lash's Sand, the junction of Koropara and Gabtola Islands, and the extension of the Koropara Sand up to the narrow neck at the northern part of Saugor Island, which may prevent the neck from being cut through as appeared imminent previously (compare Fig. 2, Plate 2, and Fig. 7, Plate 3). The opening also of the Gabtola Channel has probably resulted from the recent concentration of an increased proportion of the descending current into the Balari and Haldia Channels, as proved by their notable increase in depth, and the simultaneous shoaling of the Rangafala Channel; for the freshets coming down the Balari Channel are diverted, by the projecting points on each side of the outlet of the Haldia river, diagonally across the estuary through the Haldia and Jellingham Channels towards Saugor Island, so that the augmented current follows a course which would promote an increased scour in the direction of the Gabtola Channel between the Bedford Sands.

Condition of Approach Channels seaward of the Estuary.—The outer approach channels to the estuary which come up from deep water, though subject to some modifications, especially near the entrance to the estuary, exhibit, on the whole, considerable stability, notwithstanding the large mass of alluvial matter brought down every year by the Hooghly. These main channels, known as the Eastern Channel with the Gaspar branch above, and the Western Channel with the Middle Ground Western branch running up between projecting sandheads, or shoals, afford good deep-water access from the sea to the Hooghly estuary, a depth of 50 fathoms being reached in front of the estuary at a distance of about 60 miles south of Saugor Island, 25 miles seaward of the termination of the sandheads.

Altogether, there are no signs of any approaching obstruction or deterioration of the outlets of the main approach channels from the sea to the Hooghly estuary; the Eastern and Gaspar Channels are a little nearer Saugor Island than they were in 1888; and though the 5-fathom contour of the Western Channel has somewhat receded since 1888, its 3-fathom contour runs rather farther up the estuary than in 1888 (Figs. 2 and 7).

Navigable Condition of the River Hooghly.

In considering the navigable state of the river and the changes in its available depth, the portion above the estuary, between Calcutta and Kulpi, and the estuary itself, must be dealt with separately, as will be readily anticipated on comparing the different conditions as regards width between the surveys of the river and the charts of the estuary (Fig. 2, Plate 2, and Fig. 7, Plate 3), and is clearly exemplified by a comparison of the longitudinal sections of the river and its estuary (Figs. 8 and 9, Plate 3). In the river proper, the navigable channel follows a well-defined course, hugging the concave banks in the bends, and crossing over from one concave bank to the next below on the opposite side; and it exhibits great variations in depth in its sinuous course, with deep pools in the bends and shoals at the crossings. In the estuary, on the contrary, the great width precludes the navigable channels from following any definite course; and the choice has to be made between two or three lines of deepest water between the sandbanks, according to the available depth over the worst shoals, the stability of the channel, and the suitability of route. Whilst, however, the navigable channel through the estuary has its direction changed from time to time, on account of changes in the deep pools and intervening shoals, the differences in depth in the pools and on the shoals, and even, for the most part, the changes in depth at different periods, are much less marked than in the river.

Navigable Condition between Calcutta and Kulpi.—There are some sharp bends in the river, especially round Hangman's, Munikholi, Atchipur, Hiragunj, and Hooghly Points; but, though inconvenient and a cause of delay, owing to the tortuous course which has to be followed, the channel at these places is always stable and deep along the concave bank, with the sole exception of the channel round the bend at Hooghly Point. As regards the depth, it has already been pointed out (p. 15), that there are only three places between Calcutta and Kulpi where the depth is less than 3 fathoms at the lowest low-water—namely, at the Moyapur, Royapur, and James and Mary crossings (Fig. 16, Plate 4). Provided the depth over these shoals could be increased to 4 fathoms, there would be a continuous channel throughout of not less than 4 fathoms at the lowest low-water, and exceeding 5 fathoms for most of the distance (Fig. 8, Plate 3). In order, however, to obtain an available depth exceeding 4 fathoms, it would become necessary to lower three shoals in addition to those already mentioned—namely, opposite Hastings between Calcutta and Kidderpur, in the bend opposite Dhaja Point, and near Lower Ninan. The raising of the first of these shoals was the result of an unwise reclamation along the right bank of the river opposite Kidderpur Docks, narrowing the river at a place where it was already narrower than above or below, carried out some time between 1867 and 1882. The removal of the Ninan shoal would naturally be included in the general improvement of the James and Mary reach; but the deepening of the channel across the shoal at Fulta, opposite Dhaja Point, would involve frequent dredging; and the removal of the projecting reclamation, or frequent dredging, would be required for increasing the depth over the Hastings shoal.

Though the sharp bends, the great differences in depth of the navigable channel, and the changes in the position and depth of the channel at the crossings according to the seasons, are obvious defects in the navigable condition of the Hooghly, nevertheless, the permanence of the general course of the river renders any general regulation of the river unnecessary; and the size of the river, the large amount of sand and silt brought down, and the shifting of the sandbanks and shoals with the seasons, render extensive dredging operations inexpedient. Moreover, although apparently it would be practicable to increase the available depth in the navigable channel from less than 3 fathoms to nearly 5 fathoms at the lowest low-water, by works and by dredging at six shoals, the really important problem is the lowering of the three most obstructive shoals, so as to increase the available depth to 4 fathoms and render it permanent, and more especially the James and Mary shoal, which is occasionally a danger as well as an impediment to navigation (Figs. 7–9, Plate 3).

Navigable Condition of the Estuary.—On entering the estuary, the navigable channel undergoes a remarkable change, becoming much more uniform in depth, and on the whole shallower, except at Haldia Point, in passing through the Bedford Channel, and on entering Saugor Roads (Figs. 8 and 9, Plate 3). Owing to this general uniformity of depth, and to the lengths of the shoals with a depth over them of less than 3 fathoms intervening between the deeper channels, a material improvement in the available depth could not be effected without either extensive dredging operations in the middle of an estuary where the shoals and sandbanks are liable to shift their positions from time to time, or long, costly training-works, which in the first instance could be carried out only in the upper part of the estuary, and would be very liable to be accompanied with rapid accretion at the sides of the estuary in the slack water beyond the influence of the scour in the trained channel. An improvement is sometimes effected by natural causes, as has recently occurred from the greater concentration of the main currents in the Balari Channel, and its consequent deepening, and the opening out of the Gabtola Channel, so that the navigable channel through the estuary in the survey of 1902 is decidedly better on the whole than in 1883, notwithstanding the circumstance that the depth over the principal shoals, with the exception of the James and Mary shoal, was less in the survey of 1900–1901 than in 1883 (Figs. 8 and 9). This recent improvement, however, in the navigable channel is liable to be modified at some future time by another change in direction, as has occurred in the past; but though the variations in course and available depth depend upon uncertain conditions, the alterations in course are generally small for considerable periods, and the changes in minimum available depth slight, for as one channel deteriorates another begins to open out. Nevertheless, it must be admitted that the navigable channel through the estuary, owing to the long shoals by which it is intersected, and the changes to which it is exposed, is much less capable of any permanent improvement at a reasonable cost than is the river above.

Conclusions regarding the Improvement of the Navigable Condition of the River.—Though it would be impracticable to secure the same available navigable depth through the Hooghly estuary as in the river between Calcutta and Kulpi, the improvement of the river above its estuary to the moderate extent suggested is very important, for three reasons. In the first place, the gradual widening of the river at the Moyapur and Royapur crossings, and in parts of the James and Mary reach, is leading to a gradual reduction in the navigable depth over the crossings, and a progressive deterioration in the navigable condition of the James and Mary reach by a growth of the central shoal, an increasing divergence between the courses of the flood- and ebb-tide currents, and an augmentation in distance between the deep ebb-tide channel under Hooghly Point and the deep channel along the opposite Gewankhali shore, resulting from the continuous widening of the river at that part. Secondly, by lowering the bars at the Moyapur and Royapur crossings, and particularly by improving the condition of the channels and lowering and restricting the central shoal in the James and Mary reach, the obstructions, which the pilots regard as the most serious dangers to navigation between Calcutta and the sea, would be removed, instead of as at present growing worse by degrees. Lastly, by increasing the depth over these shoals, vessels could pass safely over them earlier on the rising tide in going down, and later on the falling tide in coming up the river, and thus have more time at their disposal for getting over the long shoals in the estuary at a suitable state of the tide.

Improvement of the River Hooghly.

Various schemes involving practically all the methods which appear to be applicable to the special circumstances of the case, have been proposed at different times for improving the navigable condition of the river at the worst places, comprising the diversion of tributaries, a new cut, training-works, dredging, and dredging- and regulation-works; but with the exception of some trial brushwood spurs carried out from the banks of the Moyapur reach about 1866, as a sort of preliminary test of the efficiency of the training-works proposed by Mr. Leonard in 1865, no works have hitherto been undertaken for the improvement of the river for navigation.

Diversion of Tributaries.—For the improvement of the navigable channel in the James and Mary reach, Mr. Longridge in his Paper, previously referred to, suggested diverting the whole flow of the Damuda into the Rupnarayan.[1]. His opinion was that as the discharge from the Damuda keeps the deep channel below Fulta Point close alongside the left bank (Figs. 14 to 16, Plate 4), the removal of this influence would cause the

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 22.

descending current of the Hooghly, hugging the concave left bank above Fulta Point, to be directed across the river by the Point to the right bank, and eventually into the Western Gut, thereby providing a stable channel through the James and Mary reach, without any bar across its passage into the deep channel running in front of Gewankhali. Besides the cost of such a diversion, and the difficulty which might be experienced in maintaining the flow of the Damuda along its new course, it appears very probable that the main current of the freshets and ebb-tide, after being directed against the right bank below the present mouth of the Damuda, would again be diverted across the river towards Nurpur by the projection of Shipgunj Point, instead of flowing into the Western Gut. Moreover, the diversion of the discharge of the Damuda from the James and Mary reach, would deprive this reach of the scour of the volume of fresh water brought into the Hooghly from this river during the rains, and of the tidal water in the dry season.

Mr. Leonard, on the contrary, considered that the James and Mary reach would be much improved if the flood-waters of the Damuda could be restored to its channel, by impounding for a time the surplus water of high floods till its inadequate channel could receive them, which at the time of his Report formed the subject of an inquiry. He further thought that if this restoration of its waters to the Damuda could be accomplished, it might be possible to divert the Rupnarayan, after restricting its discharge to that of its own basin, into the Haldia, which he was of opinion would effect a wonderful improvement in the state of the James and Mary reach, by eliminating the action of the discharge of the Rupnarayan on the flow of the Hooghly, to which he attributed the formation of the James and Mary shoal.[1] The diversion of a very large portion of the floods of the Damuda from its lower channel into the Rupnarayan, especially since 1854 when a considerable length of the embankment for controlling the floods was removed along the right bank of the Damuda, has undoubtedly contributed, in conjunction with the widening of the reach, towards the deterioration of the James and Mary reach, and particularly to the more frequent appearance of the Ninan bar after seasons of high freshets (compare Figs. 11 and 12 with Fig. 13, Plate 4). The influence of the discharge of the Rupnarayan, however, on the formation of the James and Mary shoal does not seem to have anything like as great an importance as Mr. Leonard

[1] H. Leonard, "Report on the River Hooghly," pp. 12 and 25. Calcutta, 1865.

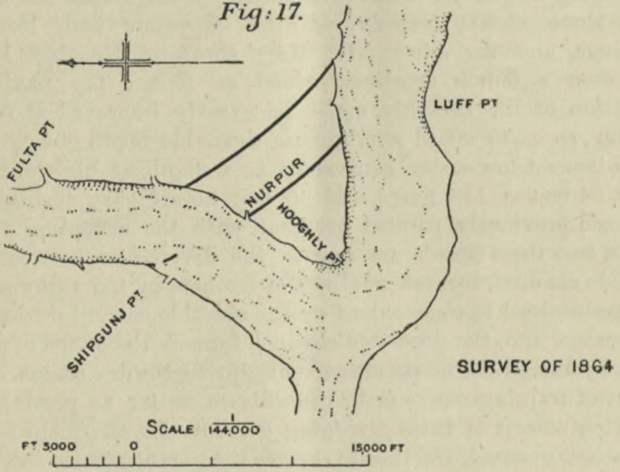
assumed, being due mainly to the very divergent action of the flood- and ebb-tides in an unduly wide reach. Accordingly, the diversion of the Rupnarayan into the Haldia would not be likely to produce any great amelioration in the condition of the James and Mary reach; whereas the withdrawal of its discharge from the section of the Hooghly between its mouth and the outlet of the Haldia, would diminish the scouring efficiency of the freshets and tides along this part, which might prejudicially affect the depth over the Kukrahati shoal at the crossing below Luff Point.

An increase of the flood-discharge of the Damuda into the Hooghly would be decidedly advantageous in augmenting the scouring efficiency of the freshets through the James and Mary reach; and this probably could be effected at a moderate expense by the repair of breaches, and the restoration of the embankment removed along the right bank. The diversion, however, of the Damuda into the Rupnarayan, or of the Rupnarayan into the Haldia, would not only be a costly work, with little prospect of effecting any improvement in the James and Mary reach, but even if either of these works fully answered the expectations of its proposer, it would affect only one reach of the Hooghly, and would require to be supplemented by other works for remedying the divergence of the flood- and ebb-tide channels following opposite sides of the river. Consequently, with the exception of an augmentation of the discharge of the Damuda into the Hooghly, by directing its flood-waters into its lower reaches as formerly by aid of the embankments, any diversion of the tributaries of the Hooghly from their present channels appears to be neither economically practicable nor expedient.

Cuts across Bends.—The remarkable stability of the course of the Hooghly between Calcutta and its estuary, in spite of a certain amount of widening of the channel and extension of the sandbanks projecting from the convex banks in the bends, naturally engenders hesitation in attempting to improve the course of the river by cuts across bends, for fear that the new straightened course, excavated through alluvial deposits of variable character, might prove more subject to erosion than the existing channel. Moreover, interference with property, and the large amount of excavation required for forming cuts equivalent in sectional area to the existing bed of the river at the diversion, would involve an expenditure which might be regarded as prohibitive. Otherwise, it is evident that a great improvement in the course of the river for navigation could be effected by cuts across the bends round Hangman's, Atchipur, and Hooghly Points (Fig. 7, Plate 3).

The formation of a cut across the projecting land at Hooghly Point, commencing near Nurpur and terminating nearly opposite Luff Point, was proposed in 1865 by Mr. W. A. Brooks, in a lecture at the Royal United Service Institution, so as to improve the course of the river at that part, and thus avoid the James and Mary shoal[1] (*Fig. 17*). His proposal was to make a small cut, and rely on the scour of the current of the river to enlarge it to the full size; but practically, to ensure the diversion of the river along the cut, it

Fig: 17.



MR. BROOKS'S SCHEME OF IMPROVEMENT, 1865.

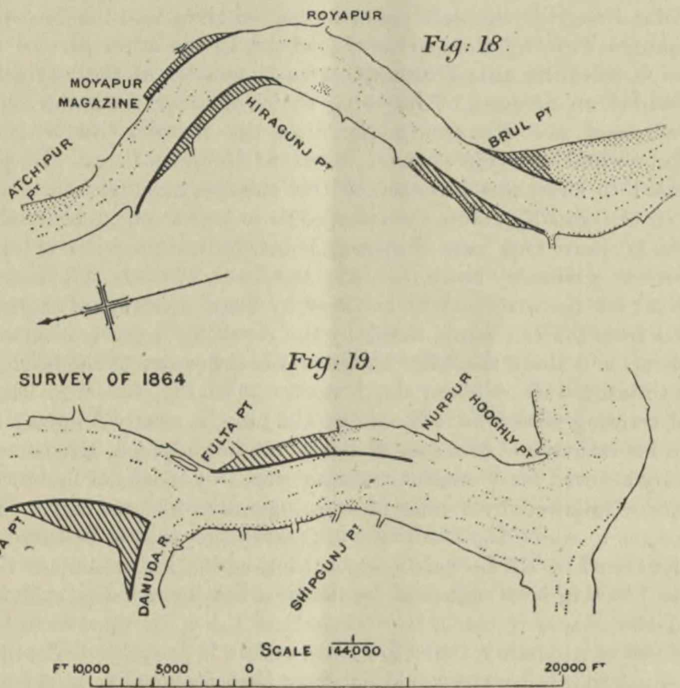
would be necessary to excavate the cut to its full size, and probably also to close the present channel below Nurpur, which would render the cut a very costly work. Moreover, as this cut would not remedy the obstruction to navigation presented after seasons of high freshets by the Ninan bar—which had not regularly developed at the time Mr. Brooks submitted his scheme—it would be necessary, in order that a cut might entirely avoid the existing obstacles in the James and Mary reach, to commence the cut a little above

[1] "The Navigation of the River Hooghly, and the proper Means to be adopted for its Amelioration, especially in reference to the dangerous James and Mary Shoals." Journal of the United Service Institution, vol. ix. (1866), p. 330.

Ninan, which would add very materially to its length, and consequently to its cost, unless, indeed, the flood-discharge of the Damuda basin were restored to the lower reaches of this river. If such a diversion of the Hooghly were carried out, it would provide a channel free from the worst impediments and dangers to navigation; and the only obstacle in the way of the accomplishment of this important improvement is the heavy cost which this diversion of the course of the river, and securing the maintenance of the concave bank of the new cut, would involve, the cost of the mere excavation of the cut proposed by Mr. Brooks having been estimated by Mr. Leonard at £1,000,000.

Training Works for lowering Shoals.—By increasing the depth over three shoals, namely, at the Moyapur and Royapur crossings, and the James and Mary shoal off Hooghly Point, and over a fourth occasional shoal at Ninan, the navigable condition of the Hooghly could be greatly improved above its estuary, so as to afford a minimum available depth of 4 fathoms at the lowest low-water, equivalent to a depth at high water of about 34 feet at low neaps, and 40 feet at ordinary springs. It has been previously pointed out that, with the exception of the Ninan bar, these shoals are due to the divergence between the ebb-tide channel, scoured out by the freshets in the rainy season and maintained to some extent by the ebb-tide current during the dry season, and the flood-tide channel formed along the opposite bank by the strong flood-tide currents during the dry season. The object of training-works is to concentrate, as far as possible, the scouring powers of these diverging currents for the maintenance of a single channel, and thus to remove the bars at present intervening at the crossings between the ebb- and flood-tide channels, and to give greater stability, as well as depth, to the navigable channel.

When, in 1865, Mr. Leonard wrote his Report on the River Hooghly to the Under-Secretary of State for India, there were only two really obstructive shoals in existence, namely, at the Moyapur crossing and the James and Mary shoal; for the appearance of a bar at Ninan after seasons of high freshets has been regularly developed only within the last 20 years; and the depth over the Royapur crossing has only fallen below 3 fathoms since 1896. In proposing the training of the Hooghly at the worst shoals, Mr. Leonard advocated the employment of brushwood spurs or groynes, projecting from the bank, as much less costly and more tentative in character than longitudinal training-works; and those spurs, by promoting silting between them owing to their checking the current, were designed, by thus raising the foreshore, to reduce the excessive width of the river in the defective reaches, and thereby eventually effect the longitudinal regulation of the river. Mr. Leonard proposed to reduce the width of the river at Moyapur, along the site of the crossing, by laying down spurs along both banks in the central portion of the reach, as shown in *Fig. 18*, and thus direct both the flood- and ebb-tide currents more into the centre of the river; and by



MR. LEONARD'S SCHEME OF IMPROVEMENT, 1865.

bringing the channels formed by those currents closer together, to scour away the central shoal at the crossing. After these works had been carried out at Moyapur, he proposed that the far less troublesome shoal at that period at the Royapur crossing should be dealt with in a precisely similar manner (*Fig. 18*). The narrowing of the river at the crossing was to be carried just far enough, by the extension of the spurs, to effect the junction of the flood- and ebb-tide channels. Some trial spurs were laid down along both banks of the Moyapur reach; but Mr. George Robertson, after inspecting the works in January, 1872, expressed the opinion that the spurs placed along the left bank for diverting the flood-tide channel, had done harm to the river by reclaiming a portion of the foreshore along that bank, and thereby impeding the flow of the flood-tide up the river.[1]

For the improvement of the James and Mary reach, Mr. Leonard proposed to direct the main ebb-tide current, flowing past Fulta Point alongside the left bank, across the river into the flood-tide channel running close to the right bank in the lower part of the reach, selecting this Western Gut as the outlet of the navigable channel on account of its being easier of access from the south, and much more free from eddies, than the Eastern Gut, which is the natural ebb-tide channel down to Hooghly Point. He proposed to effect this diversion of the ebb-tide channel from Fulta Point diagonally across the river, so as to join the deep channel of the Western Gut near Shipgunj Point, by training the ebb-tide current gradually away from the left bank towards the Western Gut: for the first part of the way by brushwood spurs extended out from the left bank, aided by the resulting accretion between them; and along the latter half, towards the centre of the reach, by a training-wall of burnt clay,[2] as shown in *Fig. 19.* The length of training-works, as indicated on the plan, is nearly 3 miles; but in his estimate of the cost of the works he proposed, Mr. Leonard only allowed for 1 mile of training-works by means of brushwood spurs, followed by 1 mile of training-wall of burnt clay.[3] The height to which the training-works were proposed to be carried is not stated in Mr. Leonard's Report; but as Mr. Robertson mentions land having been reclaimed by the trial spurs erected on each side of the Moyapur reach, it is clear that the spurs must have been raised considerably above low tide; and it is probable that at that period training-walls would not have been proposed to be raised to a less height than half-tide level. In addition to the above works, it was proposed to silt up the subsidiary channel which existed at that time along the right bank between Dhaja Flat and Fulta Sand, so as to concentrate the currents in the main channel along-

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[1] G. Robertson, "Reports to the Government of India on Indian Harbours." 2nd series, p. 17. Edinburgh, 1873.

[2] "Report on the River Hooghly," p. 29.

[3] *Ibid*, p. 32.

side the concave left bank above Fulta Point; and a spur of burnt clay was to be projected from Mornington Point to check the influx of the flood-tide up the Rupnarayan, and to divert some of this flow up the Hooghly, both of which works are indicated in *Fig. 19.*

Two further works, lower down the Hooghly, were proposed by Mr. Leonard in his Report, to be executed by means of brushwood spurs and the resultant accretion. The first consisted in joining the detached Diamond Sand to the right bank, from Buffalo Point downwards, for regulating the river between Diamond Harbour and Kantabaria, by silting up the minor channel, separating the sandbank from the right bank by carrying spurs across it, and also by promoting accretion over the whole of the Diamond shoal by extending the spurs to the edge of the navigable channel.[1] The second work was the closing of the Inner Rangafala Channel running near the left bank in the upper estuary down to Silver Tree, which had sometimes been used for the navigable channel (Figs. 7 and 10, Plate 3), and the reclamation of the deep indent in which Rangafala Island is situated, between Kantabaria and Silver Tree, by extending brushwood spurs from the left bank, so as by accretion to form a new continuous concave left bank between these points for a length of about 12 miles, projecting out into the estuary a maximum distance of 1¼ mile from the old shore-line.[2] It was anticipated that by this means a deep, stable Outer Rangafala Channel would be formed, and always maintained, by the scour of the currents keeping close along the concave left bank forming the outer edge of the land reclaimed by the training-works.

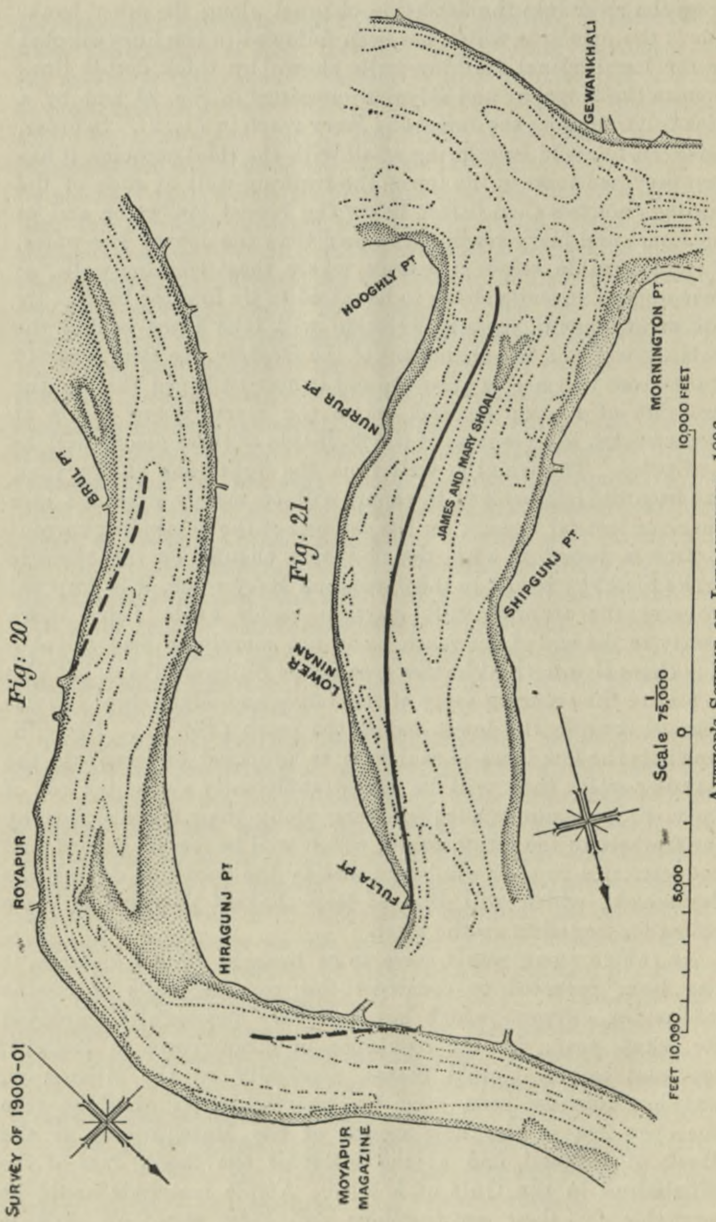
These works, proposed by Mr. Leonard in his Report nearly 40 years ago, formed collectively the first scheme put forward for the removal of all the obstructive shoals in the Hooghly between Calcutta and the estuary; and training-works were even designed to be extended down the upper part of the estuary almost as far as Saugor Island. The importance of endeavouring to train the currents so that both the flood and the ebb may form a single channel was clearly appreciated by Mr. Leonard; and the great improvement which might be effected in the available navigable depth of the Hooghly above its estuary, by merely carrying out training-works at the two or three defective crossings between the bends, was duly realized. The only features in

[1] "Report on the River Hooghly," p. 22.
[2] *Ibid*, p. 18.

Mr. Leonard's proposals which cannot be regarded as satisfactory were: the adoption of spurs instead of longitudinal training-walls; the raising of these spurs considerably so as to effect reclamations, so prejudicial in a river like the Hooghly, which is maintained solely by tidal scour during two-thirds of the year; and more especially the works designed to alter the course of the flood-tide by means of spurs across the flood-tide channels, from the left bank near the Moyapur crossing, and from the right bank near the Royapur crossing (*Fig. 18*), and by practically reclaiming the large area of the Diamond shoal by the help of spurs right across it. Curiously enough, some of the changes which Mr. Leonard proposed to carry out by reclamations produced by brushwood spurs, have since been gradually effected by natural causes to quite a sufficient extent, without involving reclamation. Thus, the subsidiary channel between Dhaja Flat and Fulta Sand has been silted up (Figs. 15 and 16, Plate 4); the minor channel between Diamond Sand and the right bank has also disappeared (Fig. 2, Plate 2); and the Inner Rangafala Channel having been practically closed, and seeming likely before long to form part of the mainland, the Outer Rangafala Channel became naturally for a time the navigable channel; and after forming subsequently an alternative to the Balari Channel alongside the right bank, as for instance in 1883–84, it has at last in its turn been superseded by the Balari Channel, which has recently become the better of the two (Fig. 2, Plate 2, and Fig. 7, Plate 3).

Fascine-Mattress Training-Walls for deepening Shoals.—A careful study of the conditions of the Hooghly shows that any works for increasing the navigable depth over the Moyapur and Royapur crossings, and in the James and Mary reach, must be designed so as to avoid reclamations from the channel of the river as far as possible, in order not to reduce the tidal capacity; and that it is absolutely essential not to offer the slightest impediment to the progress of the flood-tide up the river, so that the volume of tidal water passing up the river may be preserved unimpaired, or, if possible, increased, since it furnishes the sole scouring agency for the maintenance of the river during about 8 months of the year. Instead, therefore, of diverting the flood- and ebb-tide currents from opposite banks into a central channel at the defective crossings—which was adopted in principle by Mr. Leonard, and is at first sight a natural course to pursue in halving the diversion in each case and forming a fairly central channel—it is essential to restrict the whole of the diversion to the ebb-tide, or descending current, and to direct it gradually across the river into the flood-tide channel along the other bank. This is the principle which has been followed in the lines selected for the longitudinal training-walls shown by thick dotted lines opposite the Moyapur and Royapur crossings in *Fig. 20*, and by a thick full line along the James and Mary reach in *Fig. 21*. In order, moreover, to avoid interfering at all with the tidal capacity, it has been proposed to keep the top of the training-wall at each of the crossings not less than 6 feet below the lowest low-water, and at the James and Mary reach not higher than the lowest low-water, or if practicable below it, except where these training-walls, at their upper extremity, have to be raised to tie into the bank. By this arrangement, though accretion will take place behind the training-walls on the abatement of the freshets, the tidal capacity of the river will not be affected; and it may be hoped that by the provision of a deep channel across the river where shoals at present exist, the progress of the flood-tide at these places will be facilitated. The training-wall from the right bank at Moyapur, and from the left bank at Royapur, will be merely extended into the river just far enough for the channel of the descending current to form a junction with the flood-tide channel on the opposite bank (*Fig. 20*); whilst in the James and Mary reach, it is proposed to carry the training-wall, starting under Fulta Point, down nearly to the end of the reach, so as not merely to lead the ebb-tide channel into the Western Gut below Shipgunj Point, but also to ensure the scouring away of the James and Mary shoal in mid-channel towards the lower end of the reach (*Fig. 21*). Notwithstanding the low level at which it is proposed to terminate the training-walls, they will be raised sufficiently above the bed of the river to secure an adequate scour along their concave face, by the freshets in the rainy season, which will be merely guided and not restricted in their discharge, and by the flood-tide during the dry season, which will find a deep channel provided at these places for its influx up the river.

As rubble stone would have to be brought from a distance, it has been proposed to construct the training-walls of fascine mattresses, a system which has been very successfully employed for many years for the regulation of large rivers in Holland, and also in the United States, especially on the Mississippi, and has actually been used for training-jetties extended into the open sea at the new mouth of the Maas, known as the Hook of Holland, and at the outlet of the South Pass of the Mississippi in the Gulf of Mexico. Ample materials would be available for their construction; and they would be sunk in



AUTHOR'S SCHEME OF IMPROVEMENT, 1896.

position at slack tide, in a series of layers diminishing in width as they are carried up, and weighted with clay in bags, burnt clay, broken bricks, concrete blocks, or stone brought down the river, commencing at the upper end in a junction with the shore, and being gradually extended downwards. The training-walls would thus rest at the bottom on a very wide mattress foundation, and would be stepped well back at each successive layer, particularly on the side of the channel, to check undue erosion at the outer toe of the wall; and ample allowance would be made for the settlement of the mattresses on the alluvial foundation, especially at places where the front of the wall may be exposed to considerable scour in the formation of a deep channel across a shoal. As these training-walls are proposed to be constructed in sheltered reaches, where only scour along the outer toe of the wall, and settlement, have to be guarded against by adequate works, the section of the training-walls on the Upper Mississippi may be taken as some guide; and it would be a reckless disregard of economical considerations to propose adopting the section of the jetties at the Hook of Holland, or at the South Pass, which are fully exposed to the waves of the open sea. Fascine-mattresses are so rapidly coated over with sand and silt in a sediment-bearing river, that they are very effectually preserved from decay, even in tropical countries, as at the mouth of the Mississippi.

The essential features of this method of improving the defective reaches of the Hooghly are: connection with the bank at the upper end, to avoid the undermining of an isolated structure founded on unstable shoals exposed to scour; the provision of a single concave training-wall gradually curving out from the ebb-tide bank into the channel, so as to produce a gentle diversion of the main descending current towards the flood-tide channel (*Figs. 20* and *21*); and keeping down the top of the training-wall to as low a level as possible, consistent with obtaining a sufficient scour to form a deep channel over the central shoal, and thereby avoiding interference with the influx of the flood-tide in the dry season, and not impeding the descent of the freshets during the rains.

Dredging.—The River Hooghly is on too large a scale to be capable of having its navigable depth considerably increased by systematic dredging, such as has been so successfully carried out on comparatively small rivers, like the Clyde, the Tyne, and the Tees. Moreover, the large amount of sediment brought down by the freshets, and the changes in the bed of the river according to the seasons—so that, for instance, at Moyapur the flood-tide channel was found on one occasion to have been silted up to the extent of

21 feet in height during the freshets—would render it constantly necessary to repeat the dredging in the endeavour to maintain the depth.

The capabilities of suction dredgers for work have, however, been so much increased of late years, that such a dredger might be usefully employed in assisting training-works in opening out a channel across the sandy shoals at the crossings, and occasionally in removing a sudden obstruction in the navigable channel. Moreover, though the bars between the pools in the estuary are too long, and too liable to shift more or less, to be capable of being effectually lowered by sand-pump dredgers, it might be possible at times to assist the opening out of a new channel in process of formation, by cutting across a narrow shoal obstructing the flow; and bars might sometimes be lowered 2 or 3 feet by a dredger, so as to increase the available navigable depth to this extent where the length of shoal at the highest level is short. It might also be practicable, by judicious dredging at certain parts of the navigable channel in the estuary, to promote the stability of the existing channel, or to hasten a desirable change of route. Beyond this, however, dredging does not appear applicable for the economical or permanent improvement of the Hooghly.

Dredging and Regulation.—The latest scheme for the improvement of the Hooghly, in the three defective reaches above its estuary, was explained by Mr. Lindon W. Bates, a constructor of powerful suction dredgers with revolving cutters, in a lecture which he gave at Calcutta, before the Harbour Commissioners, in February, 1899. He prefaced his proposals for the improvement of the river by stating that the Moyapur and Royapur shoals were the most difficult to deal with; and he propounded the following axioms:—" The normal form for a tidal river is that of a wedge, and this development of the river into a straight line . . . indicates that it generally follows this formation, but with enlargements at places, and each of these enlargements is a source of trouble;" and further on, "Nothing should be put into a river on its cutting bank; such works are difficult to make and maintain, and all training-works should be above the highest water-level."[1] The views thus expressed serve to explain the works proposed by Mr. Bates for improving the Moyapur and Royapur reaches; for having naturally

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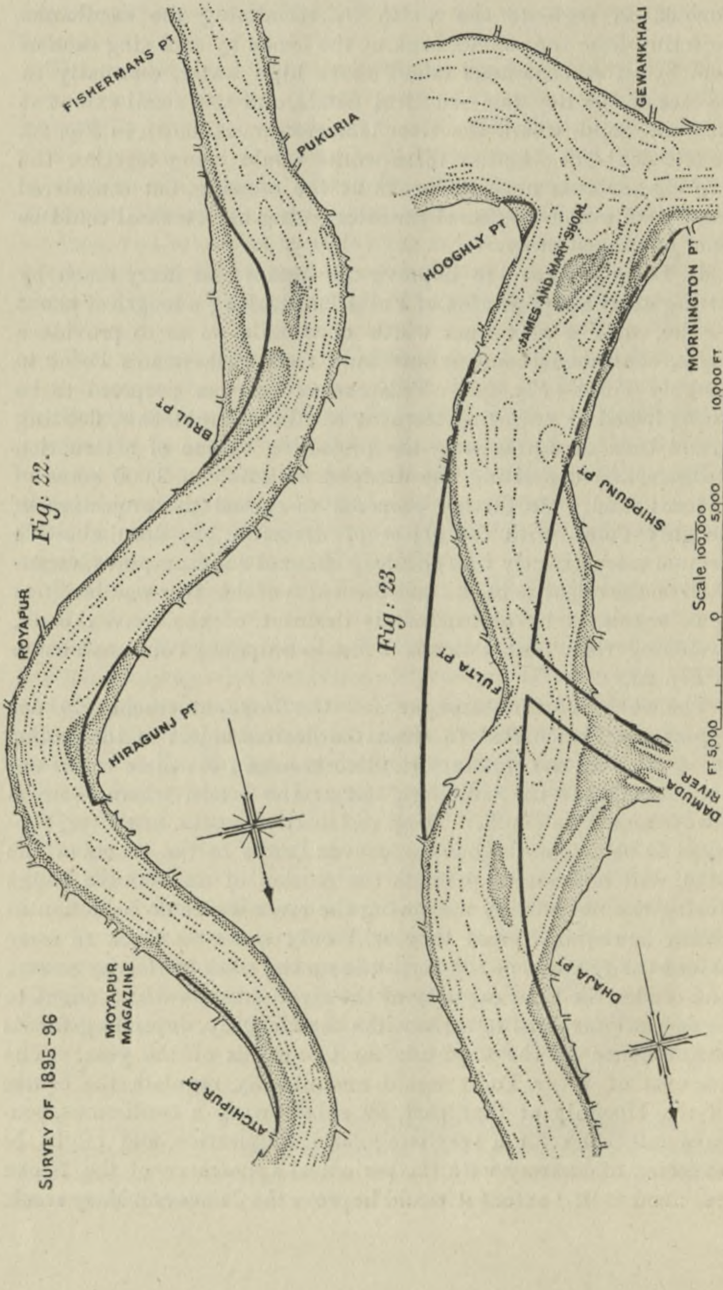
[1] "Lecture given by Mr. Lindon W. Bates, on the 6th February, 1899, to the Commissioners for the Port of Calcutta, on the measures he would recommend to be adopted for the improvement of the River Hooghly between Diamond Harbour and Calcutta."

found that the river is wider in the bends than elsewhere, he proposed to regulate the width by reclaiming the sandbanks projecting from the convex bank at the bends by enclosing each of them by an embankment raised above high water, especially in the case of the Royapur and Brul Sands, and to a small extent at Atchipur Sand, where the river is narrower, as shown in *Fig. 22.* He felt doubtful whether these works would bring together the deep channels on opposite banks at the crossing, but considered that if this were not effected the intervening narrow shoal could be rapidly dredged away.

Mr. Bates proposed to improve the James and Mary reach by cutting away the projection of Fulta Point, along a length of about 3 miles, with a maximum width of $\frac{3}{4}$ mile, so as to provide a single, continuous, concave left bank from Fisherman's Point to Hooghly Point (*Fig. 23*). This excavation was proposed to be accomplished by enclosing the area within embankments, flooding it, and then dredging away the projection by one of his suction dredgers, and depositing the dredged material on 2,000 acres of adjacent land. He further proposed to extend the projection of Hooghly Point, with the object of diverting the deep ebb-tide channel more directly into the deep channel running past Gewankhali on the opposite bank; and the width of the river was designed to be regulated by embankments in front of the convex bank, stretching from near Pukuria Point to Shipgunj Point, as shown in *Fig. 23.*

The works at the Moyapur and the Royapur reaches do not appear at all calculated to effect the desired object of increasing the depth over the crossings in these reaches; for these works are not placed near the crossings, but at the bends, where there is always an ample depth. These reclamation-works, moreover, proposed to be extended from the convex banks in the centre of the bend, will necessarily promote the erosion of the concave banks during the freshets, by narrowing the river where no reduction in width is required; and they will only serve to check to some extent the progress of the flood-tide up the river in the dry season, and reduce the tidal capacity of the river—results which ought to be specially avoided in a river like the Hooghly, depending for its maintenance on the flood-tide for two-thirds of the year. The removal of Fulta Point would undoubtedly regulate the course of the Hooghly at that part, by substituting a continuous, concave left bank for a very irregular configuration, and might be expected to do away with the periodical appearance of the Ninan bar; and to that extent it would improve the James and Mary reach.



Mr. Bates's Scheme of Improvement, 1899.

Unfortunately, however, the main obstruction and danger to navigation is the James and Mary shoal at the lower end of the reach, which would not be materially modified by the cutting off of Fulta Point. The main descending current always follows close along the left bank from near Nurpur down towards Hooghly Point; and a deep channel is invariably found at this point in the surveys. Accordingly, whilst the navigable channel would be distinctly improved in the upper part of the reach by the regulation of the left bank, there is no reason to expect any material improvement in the lower part of the channel, which is always deep, beyond possibly a slightly increased scour during the freshets, owing to their more direct course. In the dry season, moreover, the antagonism between the flood- and ebb-tide currents round the sharp bend would not be in the least affected by the removal of Fulta Point, and in fact would be somewhat increased by the proposed extension of Hooghly Point; and so long as this conflict of forces and divergence of channels continues, there is no prospect that the shifting bar across the ebb-tide channel off Hooghly Point will disappear, or the dangerous eddies in this part of the navigable channel be diminished.

The concentration of the flood- and ebb-tide currents into a single channel is the only true solution of the difficulties in the lower part of the James and Mary reach; this cannot be effected by the removal of Fulta Point, which aims at the improvement of the Eastern Gut; and the sole method of doing away with the divergence of channels and conflict of currents in the sharp bend round Hooghly Point, with the consequent shoals, is by directing the descending current into the Western Gut.

Concluding Remarks.

In conclusion, the Author desires to express his best thanks to the Calcutta Port Commissioners for having supplied him with copies of all the sheets of surveys of the river, and charts of the estuary, issued by their Survey Department since 1896, which have been of great value in the preparation of this Paper, for noting recent changes in the river and its estuary, and thus tracing the history of and the changes in the river from the earliest reliable charts down to that of 1902, which was the latest survey of the estuary when the Paper was written. He also wishes to state the great importance he attaches to the records of the condition and changes of the River Hooghly, between Calcutta and the sea, furnished by the periodical surveys of the river, and frequent charts of the estuary, inaugurated by Mr. E. W. Petley, on his taking charge of the Survey Department about 20 years ago, which throw so much light on the navigable conditions of the river, its needs, and the possibilities of improving it. He ventures to hope that the account of a very interesting and peculiar river given in this Paper, founded upon very careful investigation and study of all the available charts, may be of interest to members of the Institution, and also serve to indicate the kind of improvement needed, and the extent to which it may be feasible to carry it out. He further trusts that the Paper may furnish a basis for the design of some thoroughly satisfactory scheme for the improvement of the river which many persons have despaired of accomplishing, whilst others submitted proposals for its amelioration long ago. After most careful consideration, the Author has come to the conclusion that there is no feature in the condition of the Hooghly which renders it incapable of a moderate amount of improvement above its estuary, and that, in the interests of the Port of Calcutta, the improvement of the river, to the extent which its physical conditions render reasonably attainable, should not be longer delayed.

The Paper is illustrated by three plans and four tracings, from which Plates 2, 3 and 4, and the Figures in the text, have been prepared.

Discussion.

The PRESIDENT moved a vote of thanks to the Author for laying before the Institution, in so interesting a manner, the difficulties which beset the navigation of the River Hooghly; and he expressed the hope that the Paper would form a basis for measures for the improvement of the river. The President.

The AUTHOR observed that he ought to mention a project known as the "Luff-Point scheme," which had been proposed since the Paper was written. Luff Point was a little below Gewankhali; and the proposal was that the Bengal-Nagpur Railway Company should choose some place on the right bank in the lower part of the Hooghly, where they could build jetties and form a coaling-station, and in that way avoid the James and Mary shoal and the shoals higher up the river. Such a station could be established near Gewankhali, where there was always deep water close alongside the right bank. The only objection, as regarded suitability, that might be raised against that site was that considerable erosion took place there, amounting, according to information he received in 1896, to about 8 feet per annum. He understood, however, from Commander Jarrad, who had advised the Company in regard to the navigation questions in connection with the proposed scheme, that that figure was somewhat larger than the actual amount. No doubt, if a coaling-station and jetties were established near Gewankhali, and if the erosion of the banks did not form an obstacle, the impediment to safe navigation offered by the James and Mary shoal would be obviated. The real objection to the scheme, however, was the important change it would effect in the route of navigation, and the removal from Calcutta of the trade it had always possessed. The Author.

Mr. J. H. APJOHN remarked that he had been responsible for the Author's visit to Calcutta to report on the Hooghly, and he thought the Institution was indebted to the Author for having put on record the history of that river in a form which would always be available in the consideration of any scheme for its improvement. When it came to an actual scheme, there was a wide difference of opinion on the subject. It was, he admitted, quite possible that the Author's proposals, if they could be carried out, might effect an improvement; but the question was, could they be carried out at any reasonable cost? The Author's estimate was £170,000; but, Mr. Apjohn.

Mr. Apjohn. speaking as one who had carried out works in India for many years, Mr. Apjohn considered that the work would cost about six-and-a-half times that amount. He might be wrong; but the very difference between the estimates showed how difficult the question was, and how hopeless it seemed to produce a scheme convincing enough to induce any public body to sink an enormous sum in what must be an experiment. But was the river quite as bad as was made out? He did not think there really was such great necessity for its improvement. Instead of getting worse, it seemed to him to be getting better. He had recently received curves of the Moyapur and James and Mary shoals, which showed a steady improvement in the last 20 years, and indeed a striking improvement since the Author visited the river. It was natural to think, as the Author did, that the gradual widening of the reaches must lead to a deterioration; but they had been widening for the last 20 years and yet for the same period they had been improving in depth. The draught and size of the vessels visiting the Port of Calcutta were increasing continually. In 1904 a vessel drawing 28 feet 3 inches made many voyages up and down the river with safety. Such a thing would have been regarded as incredible 20 years ago. He ascribed that not so much to the improvement of the river as to the improvement of the surveys of the river under the very able administration of Mr. Petley, who for the last 25 years had administered that department of the Port Trust. Twenty years ago only 1,225 miles were sounded every year, while in 1904 7,678 miles were sounded. Twenty-five years ago only 20 charts and notices were issued in the year; in 1904 there were 1,093 daily notices and small charts of the changing bars, which enabled the pilots to take the best course instead of the old system of following a straight track. There had also been a large increase in the number of buoys and river-marks, which had been increased in the period from 7 to 44, and from 57 to 138, respectively. Therefore it would seem that the improvement in the navigation of the Hooghly was due not so much to the river itself as to the surveying of it. The river-authorities could not afford to experiment, at the cost of, say, a million sterling, with works which might do harm—especially while they were being carried out. Even the Author's proposed training-wall might lead to serious trouble before it was completed. Although he did not entirely agree with all the details, he preferred Mr. Lindon Bates's proposal; at any rate, the works Mr. Bates proposed could be carried out with certainty, and there was no engineering difficulty about them. He would be rather inclined to change slightly the position of some of these walls; and whether they should be above high tide or only up to half-tide level was an open question. He was disposed to agree with the Author that they should not be up to high tide. He was of opinion that the Author's wall should be above high-tide level, because otherwise he was certain it could not be carried out. Mr. Apjohn.

Commander Jarrad.

Commander F. W. JARRAD, R.N., pointed out that the Luff-Point scheme submitted to the Government of India by the Bengal-Nagpur Railway Company, had really, among other reasons, been taken up in order to avoid the upper reaches of the river and the dangers attending navigation. Eventually a place lower down the river than that suggested by the Author had been selected, where there was deep sheltered water and facilities for mooring vessels in quietude, with suitable sites for jetties or docks. The scheme had been brought forward in the interest of the Bengal-Nagpur Railway Company, in order to get a better share in the coal-trade than they were getting by taking their coal across the river at Calcutta by ferry—a very unsatisfactory procedure. The proposal was to bring a short line down from Panchkura, one of the Bengal-Nagpur stations, to near Luff Point. Attempt had been made to greatly minimize the undoubted physical advantages of the proposed site by the opposition of the Port Trust of Calcutta, who not unnaturally preferred to load coal at Kidderpur Dock, in order to keep up their revenue, which they feared would fall off if the scheme were carried out. That idea had been exploded of late years. The building of Barry Docks had been supposed to threaten the trade of Cardiff, instead of which Cardiff had progressed; and the same would apply to Calcutta. The proposal was essential to the development of the coal-trade. He did not agree that the river could not be improved, nor did he agree that it was really improving itself in a measure, because his investigations went to show that the Author's statement that it was deteriorating was right. He knew that when he was in the Indian Survey years ago there were far fewer places in the Hooghly which gave trouble than there were at present. The Calcutta authorities had, he understood, ordered a very powerful dredger to dredge the shallows—a fact which did not indicate that the river had improved. Naturally the river would be improving about the present time, because it was just after the rainy season, and a period when the channels were really at their best. The Author had done great service in bringing together in the Paper the various schemes that had been put forward. It would be a great advantage if some scheme could be formulated, although

Commander Jarrad. he thought the river had suffered from having "too many cooks." If only the Government of India could take up the matter and get the advice of competent engineers, he had no doubt the river could be dealt with to the great advantage of the port of Calcutta.

The Author. The AUTHOR, in reply, observed that there were three places where, as he had pointed out, the river was evidently deteriorating, namely, at Moyapur, Royapur, and the James and Mary reach. He was much surprised that Mr. Apjohn said the river had been improving during the last 20 years. He did not know what had occurred in the last 2 years; but certainly in the latest surveys that reached him up to 1902, the Royapur crossing had a bar with less than 3 fathoms over it at the lowest low-water; whereas when he was in Calcutta in 1896 there was no 3-fathom bar at Royapur at all, although it looked as if there would be a bar there in the future, as the river seemed to be deteriorating at that crossing. Moreover, the Moyapur crossing was obviously in a much worse state in 1900 than in 1883 (Fig. 8, Plate 3; and compare Figs. 14 and 16, Plate 4); and it was pointed out in the Paper that the surveys showed a gradual deterioration of the James and Mary reach. He agreed, however, with Mr. Apjohn's subsequent qualifying remark that most probably the fact that the river was now navigable by larger vessels than it was 20 years ago, was due to the very good surveys which had been carried out, under the direction of Mr. Petley, and the large number of notices issued to the pilots at frequent intervals, giving the existing depths over the worst shoals. But these precautionary measures could not be increased indefinitely, and very soon it would become absolutely necessary to do something to improve those particular bars in the river. He was sure it would not be beyond the resources of engineers to find a means by which the depth over these bars could be increased, and the deterioration of these particular reaches by progressive widening could be arrested. Moreover, though it might be beyond the capabilities of engineering science to improve the estuary beyond a moderate amount at a reasonable cost, a powerful suction dredger might lower the highest parts of the bars and help the channels to develop as they changed.

The President. The PRESIDENT observed that the James and Mary shoal constituted a very serious danger to the navigation of the Hooghly, from the fact that when a vessel touched on the sand it was, as a general rule, lost in a few minutes; the ship heeled over and was sucked in. Only lately he had received a graphic description of such an occurrence from a lady who was going down the river. She was in her cabin, when suddenly she found the ship on its beam ends, and she was just in time to crawl through the port-hole and climb outside on to the bulwarks, from which she was rescued by a steam-launch. He had passed over the James and Mary shoal between thirty and forty times, and always with a feeling of relief when the passage was over. If anything could be done to improve the shoal it would be of considerable benefit, but any work undertaken would entail dealing with very large volumes of water, and would be work of considerable difficulty and expense. Moreover, with such complicated conditions as existed in the Hooghly the result must be always a matter of uncertainty. While improvement might be effected in one place, at the same time conditions might be set up which would make matters worse in another place. The question of taking the trade away from Calcutta was a very important one. The peculiarities of the coal-trade might of course enable this objection to be met by chartering special vessels; but an unsuccessful attempt had already been made to establish a port at Port Canning, on the Mutla river, by which the difficulties of the James and Mary shoal would have been avoided, and navigation simplified; but it was found impossible to draw the trade away from Calcutta, where the merchants' houses were established. The character of the foundations in this delta might be gauged from the fact that, when some cast-iron cylinders for foundations had been sunk to a depth of about 30 feet, they suddenly disappeared, and no trace of them could be found. The President.

Correspondence.

Mr. E. S. Bellasis observed that when a stream flowed round a curve the cross section of the stream was unsymmetrical, there being a deepening along the concave bank and a shoaling along the convex bank. In straight reaches, or at the "crossings" where one curve ended and another, bending in the opposite direction, began, the section was symmetrical. The deep stream tended to hug the bank more just below a bend than just above it. Hence, in a tidal stream which flowed sometimes in one direction and sometimes in the reverse direction, the flood-tide might tend, near Mr. Bellasis.

Mr. Bellasis. sharp bends, to form separate channels of its own. The flow in a stream would be least disturbed, and the regime best, when the curves were gentle and the width constant and properly suited to the discharge. This arrangement should be aimed at in training-works, and a channel so arranged would be suited for flow in either direction. In the case of the Hooghly the Author had shown that, owing to sharpness or irregularity of the bends, or to widening in some places, the flood-tide in some reaches tended to run in channels other than those taken by the ebb-tide, that central sand-banks were thus formed, and that the evil seemed to be increasing. The remedy should consist in narrowing the channel and making the curves gentler. The Author was anxious not to interfere with the progress of the flood-tide of the river. There had recently existed a school of engineers who laid it down as a fixed principle that in a tidal estuary no training-works should be undertaken which would reduce the capacity of the channel and interfere with the entrance of tidal water. This school should logically (as had been remarked in previous discussions at the Institution) have objected to the Thames Embankments. If a channel was narrowed, and the volume of the flood-tide was thus reduced, the width to be kept open was also reduced. The places in the Hooghly where works were suggested were so far from the sea that the moderate contractions proposed could not interfere with the volume of tidal water entering from the sea, nor could they much affect the volume passing up above them. It seemed that formerly the river had been narrower, and yet better for navigation, and suitable contractions would restore its efficiency. Moreover, to contract a channel and yet leave it as capable as before of passing tidal water seemed to be impossible. Just as it was impossible by means of oblique weirs—or by any means except movable weirs—to hold up low discharges and yet not obstruct floods, so it was impossible to build training-walls which would narrow a stream at ebb-tide and yet not obstruct the flood-tide. If the tops of the walls were kept below the lowest water-level as proposed, they would hardly be likely to produce the required result. The general alignment of the walls seemed to be suitable, but, unless the spaces behind them completely silted up, their down-stream ends might be caught by the flood-tide, scour-holes be formed, and the walls be damaged. It would be preferable to curve the ends of each wall in towards the bank from which it started. Since gentle curves were best, a cut such as that discussed on p. 33 might be a great improvement, but, owing to its cost, the training-wall proposed seemed preferable. He entirely agreed with the

Author in his remarks on the unsuitability of dredging in the Hooghly and in his preference of longitudinal walls to spurs. The blind channels mentioned by the Author did not seem to be due to the action of the flood-tide, for similar formations existed in non-tidal rivers. The sand tended to accumulate just alongside the flowing stream and thus to form spits; and between these spits and the bank proper there were left back-waters or blind channels. Mr. Bellasis.

Mr. G. Bozdech, Engineer for the Regulation of the Danube, mentioned that of the 118 miles of the Danube in Lower Austria, with which he had to deal, about 15½ miles ran through solid rock, but for the remaining 102½ miles artificial banks confined the mean channel to a bed through stony ground, in which boulders were kept in constant movement, especially during times of flood. The ratio of the minimum to the maximum flow was 1 : 15, the fall was 1 in 2,000, and the rate of flow in flood-time was 11·8 feet per second: whereas in the Hooghly only mud and sand were met with, the ratio of the minimum to the maximum flow was 1 : 30 and even 1 : 60, the fall was very slight, and the river was tidal. Consequently it must be doubtful whether the methods adopted in the training of the Danube were applicable to the Hooghly, and whether the experience gained on the former afforded a sound basis for criticism of the proposals in reference to the latter. Nevertheless, he might state that on the Danube the efforts at the present time were devoted to so directing and preserving the main stream in a serpentine line, complying with the natural conditions and adapted to the needs of those on shore and the requirements of the navigation, that the channel might maintain an unchanging position, and in this position might retain a depth of not less than 8·2 feet at dead low water, even at the junction of two bends. Endeavour was made to utilize existing serpentine deviations for maintaining the course of the stream in concave bends, to produce no straight reaches, and therefore to avoid cuttings. In the most recent work, training-walls were employed only on the bank against which it was desired that the current should pass, the stream being forced away from the opposite bank by groynes. At the junctions of bends the current was forced by groynes away from both banks, into the middle of the river. The groynes themselves were not intended to reduce the profile, but only to serve as skeletons to give a suitable shape to the bed of the stream; they were therefore placed beneath the low-water line and had no obtrusive forms, but approached in outline the shape which the natural gravel banks would assume where they bordered a well-formed channel. Mr. Bozdech.

Mr. de Coene. Mr. J. DE COENE, of Rouen, pointed out that the Hooghly had many points of analogy with the Seine between Rouen and the sea. The distance between Calcutta and the sea was 100 miles, that between Rouen and the sea was about 80 miles. The tide flowed up to Calcutta, as it did to Rouen, and the action of the flood- and ebb-tides extended along the river as well as the estuary. The only difference was the greater volume of fresh water in the Hooghly during the rainy season. The rise of the tide was greater in the Seine than in the Hooghly. The action of the tides was the same in the beds of both rivers, and the channels in the estuary were modified by tidal action. The views put forward by Mr. P. Bouniceau[1] with respect to the problem of the improvement of tidal rivers were now definitely accepted, and their correctness had been shown by the works carried out on the Maas by Mr. P. Caland, and those executed on the Tees by Mr. A. F. Fowler. To the application of Mr. Bouniceau's methods, the use of dredging had been joined, which had now assumed considerable importance, and had enabled Mr. Lyster to secure in the Mersey at all hours and for the largest vessels access to the port of Liverpool, and to the entrance of the Manchester Ship-Canal. The use of dredging had so great an influence upon maritime works, that it even seemed to some engineers that the action of the tides on river-beds might now be deemed to be of less account than the effects of dredging operations, as, for example, in the case of the projected Thames barrage at Gravesend. The dredger was able to enter effectually on a contest with the tides, for forming and maintaining the channels in rivers along their course, and at the point of their discharge into the sea; as for instance in the Mississippi, where Dr. E. L. Corthell had shown that, in conjunction with the continuous action of the currents which issued from the embanked channel of that river, the dredger was able to assure the lowering of the bar. In fact, bars such as those of the Mersey and of the Mississippi were unable to withstand the action of the current, when supplemented by dredging. Finally, dredgers served to assist powerfully the action of the current set up by the construction of training-walls, in keeping the passes in good condition. The Maas, which formerly emptied itself into the sea through a sandy delta, by numerous shallow and variable channels, now discharged by a

[1] "Étude sur la navigation des rivières à marées et la conquête des lais et relais de leur embouchure." Paris, 1845.

single outlet, where, thanks to the movements of the flood- and ebb-tides, and to important dredging-works, it had been possible to establish and to maintain a single invariable channel, which gave complete satisfaction, and reflected the utmost honour on the engineer who conceived and carried out the works with a perseverance which had conquered all the obstacles placed in his way. The Mersey was also a case in point. Professor Osborne Reynolds had shown experimentally that in wide estuaries the channels changed their direction periodically, and had demonstrated the necessity for contracting the width of rivers and for compelling them to pass into the sea through a single outlet. The deepening of the passes effected in this way enabled the flood-tide to ascend with greater facility into the upper reaches of the river, and adapted it better to carry away in its descent to the sea the material eroded by floods in the river. The success of the works on the Maas, on the Mississippi, and on the Tees, afforded the most striking examples of this. The Weser, also, had been completely regulated in its maritime section, between Bremen and the sea, by Mr. L. Franzius. The fact that the estuaries of certain other rivers—*e.g.*, the Garonne, and the Elbe—had not yet been improved, must be ascribed to the timidity of the engineers charged with the execution of the necessary works. He had referred to the foregoing examples in order to explain how, in his opinion, it would be advisable to proceed in the case of the Hooghly, the importance of which as a maritime means of communication was enormous, and which did not at present comply altogether with the requirements of navigation. The longitudinal section of the river (Figs. 8 and 9, Plate 3) might be divided into two distinct portions, namely, the channel between Calcutta and Balari, with a length of about 60 miles, which formed the maritime part of the river, and the estuary, which extended from the 60th to the 100th mile. The first of these portions could, and should, be progressively improved by training-walls and by dredging, such as had been carried out in the Seine, the Tees, and the Weser, by nearly identical methods. Sometimes training-walls might be used, supplemented by defensive embankments, forming two channels, a deep navigable channel and a channel for heavy floods—such, for instance, as might be seen in the works on the Tees, and especially on the Weser. The arrangement of the embankments should vary in accordance with the configuration of the localities, and taking into account the discharges of tributaries. On this point he was in agreement with the Author. Works of this kind must Mr. de Coene.

Mr. de Coene. effect very sensible improvements in the maritime channel, and must assist the action of the tides passing up from the estuary. With respect to the estuary which extended from the 60th to the 100th mile of the Hooghly, it appeared to Mr. de Coene that, at the present time, the depths of the soundings varied but little; the channel was fluctuating and subject to important changes in its direction, just as in the Seine and in all very wide estuaries before the execution of improvement-works. It seemed to him that, in this part of the river, the improvements must be carried out upon a different plan from that applicable to the other part. Choice should be made between the two principal tracks which existed in this portion; and upon the question whether the present channel should be preserved, or that named the Western Channel should be chosen, his opinion was that the definite channel should be located in the western portion of the estuary, instead of being retained in the midst of the sandy islets dispersed over the channel now frequented by vessels, which had to be guided at night by light-ships. The works should be commenced at the lowest point of the river and should be pushed up-stream, as had been done on the Maas in making first the cut across the Hook of Holland. This was what he had proposed to do in the case of the Seine,[1] beginning with the northern channel, and then directing the training-walls upwards so as to meet the main channels. The use of large training-walls, formed of fascine-work, of the kind employed on the Mississippi, seemed to be suitable for this purpose. This would provide a means of undertaking, in considerable sections at a time, the requisite training-works for the channel, which could be supplemented by heavy dredging. Low training-walls would probably suffice. It would then become possible to lower the bar at the entrance of the river in such a way as to render possible the admission of vessels of deep draught, even at low water, and thereafter gradually to reduce the height of the plateau which extended between the western channel and Diamond Harbour at the sixtieth mile, at which latter point the available depth was at present considerable. These works were certainly of considerable magnitude; but the object to be attained—namely, to provide access at all times, and even at low water, into a trained and regular channel—would be of immense benefit to the port of Calcutta,

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[1] "La Seine maritime au point de vue du commerce et de la défense nationale." Bull. de la Société Industrielle de Rouen, 1904. Also Minutes of Proceedings Inst. C.E., vol. cxviii. p. 170.

because these operations would produce a sensible effect on the works needed in the higher reaches of the river, by assuring the arrival of the flood-tide in much greater volume, and in securing also a more easy and regular discharge both for the ebb-tide and for the fresh-water floods which were so abundant in the river during the rainy season. With the novel appliances which were now available, there would be no insurmountable difficulty in converting the Hooghly into a magnificent waterway, yielding to the commerce of the Port of Calcutta resources and economies, and avoiding the great dangers to which navigation was exposed at the present time, owing to changes in the variable channels. The results attained in the case of the Mississippi afforded a sure warranty of success, and were such as to admit of the belief that the amelioration and deepening of the channel giving access to the Port of Calcutta would be realized. Mr. de Coene.

Dr. E. L. Corthell, after examining the various propositions for improving the shallow reaches of the Hooghly, could but come to the following conclusions :—In a river such as this—with an extremely mobile bed, a large amount of sedimentary matter in suspension, and a tortuous course—the only feasible plan seemed to be to restrict the remedial measures to dredging alone, adopting a plan ably presented to the Paris Navigation Congress of 1900 by Professor V. de Timonoff, of Russia, and called "The Attraction of the Waters." It consisted in investigating by current observations and by surveys where the river itself was likely to make its channel, keeping it open at low water particularly, and dredging any shoals and bars lying between the deep pools after the subsidence of the floods: exactly as was now being done on the Mississippi River, where nine or ten powerful suction-dredgers were set to work immediately after the subsidence of the spring and early summer floods, to make new channels or to restore old ones closed by the river during its flood stage. It was found that the channels were gradually being maintained, in spite of the fact that the river brought down an immense amount of sediment in its annual floods; and he was of opinion that the lessons learned on the Mississippi River could be properly applied to the conditions of the Hooghly. Dr. Corthell.

Mr. H. Crahay de Franchimont, of Paris, deemed it necessary to consider the question of the improvement of the Hooghly simultaneously from two different points of view :—I. The regulation of its course at the present time, and the future maintenance of such regulation. II. The removal of the chief obstacles to navigation. I. The river appeared to be a tidal one, with a very shifting bed, Mr. Crahay de Franchimont.

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and with an outlet moderately obstructed by sandbanks, in which the conditions for the tidal flow and the permanence of the depth of channel were at the present time fairly favourable. Between Khijiri and Hooghly Points the low-water line was approximately horizontal, and it was only above the latter point that it began to rise slowly; while the level of high water, which was horizontal as far as Calcutta, afterwards dropped slowly as far as Nadia, where it was about 23·6 inches below high-water line at the mouth of the river. This was a characteristic feature of the Hooghly, as compared with the Adour, the Dordogne, the Gironde, the Loire, and the Charente, and one which could scarcely be found to prevail anywhere in France except in the Seine, and there only in reaches affected by the bore. In the Hooghly, as in the Seine, there occurred an important bore, which, however, was less marked than certain writers had stated, for, according to the Author's figures, the height of the wave did not appear to exceed a maximum of 5 feet 4½ inches, at Chinsurah. If it were taken for granted, as certain writers on hydraulics had affirmed, that this phenomenon was caused by the excess of the volume of water which the sea poured into the river in a given time over the volume due to the increment in the amount of water gained in the same period by the river-tide, the waves whose crests constituted the bore must be formed in the vicinity of Hooghly Point, during the second period of tidal flow; and if it were borne in mind that the low-water line ceased to be horizontal up-stream from this same locality, this spot would naturally be fixed upon as the starting-point of the estuary: whereas the geographical limit of the river would naturally be located on the line between the Saugor lights and the mouth of the Rasulpur River. It followed that the projects for the improvement of the water-way should relate to two distinct portions of the river; the first, extending from Nadia to Hooghly Point, would comprise the whole of the river which, properly speaking, was subject to tidal influences; the second would be the estuary between Hooghly Point and the geographical outlet into the sea. It was to the first of these sections that the following observations specially related; but he might state generally that, whatever schemes of improvement were contemplated, it appeared essential that regard should be paid mainly to the tidal portion of the river, because it was here that remedial treatment was urgently called for, beyond all other considerations, throughout two-thirds of the year; while the floods in the rivers which discharged into the upper basin, such as the Matabanga, the Jellinghi, and others, and those of the lower basin, such as the Damuda and the Rupnarayan, could only be regarded as accidental phenomena, which interfered with the mean and permanent condition of the river, by tending temporarily to deepen certain channels, or, on the other hand, to deposit alluvium in certain parts of the river-bed. If the tidal condition of the Hooghly was on the whole fairly satisfactory, it might be said, also, that from the charts of soundings and the longitudinal sections taken at different periods, which were put forward by the Author, the conditions under which the depths of channel were maintained were on the whole equally favourable. But, owing to certain local circumstances, and especially to the confluence of the Damuda and the Rupnarayan, the contour plan of the river was defective in several parts; consequently there was a marked discrepancy between the ebb- and flood-currents which gave rise to serious difficulties in the navigation, more especially at Buj-Buj, at Moyapur, at Royapur, and chiefly in the vicinity of Hooghly Point, on the James and Mary shoal. This was, indeed, a very general condition of affairs in tidal rivers. In these circumstances, and taking into consideration the great mobility of the river-bed, he was led to believe that the Hooghly had moulded the form and capacity of its bed into a position of equilibrium which varied but little from time to time, and which was in conformity with the volumes of the ebb- and flood-tides. On this account its mean transverse section at each point—meaning thereby that section which corresponded during the dry season with the mean speed of the current throughout an entire period of flood- and ebb-tides, at the epoch of ordinary syzygies—was the most important factor to be taken into consideration, because it corresponded with that action of the tidal currents which was most normally effective, and with the most usual condition of the river, about which its variations tended to oscillate. The diagrams which accompanied the Paper did not enable him to calculate these successive sections between Nadia and Hooghly Point, because no transverse sections were given; and those which were appended to the Author's Report of 1896 made no mention of the slack water on the flood- and ebb-tides, the consideration of which was indispensable for such calculation.[1] But there could

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[1] If T represents the duration of the flow and T′ the duration of the ebb, the variations in the total section, showing the discharge of the river between two consecutive ebb-slacks, for instance, will be represented by a periodic curve of

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be no doubt that the local river-conservators possessed all the data needed for this calculation, and it would therefore be interesting to construct from them the following diagrams. On two axes of co-ordinates should be set off in abscissæ the lengths of the river as developed, while for the ordinates the mean transverse sections at flood-tide should be taken at the most remarkable points, and principally at those where the stability of the bed had been mainly observed; and in this way there would be obtained the law governing the succession of these sections. A second graphic diagram should similarly be prepared for the mean sections at the ebb-tide. It would then become possible to trace the two continuous curves corresponding with the mean law of variation; and these curves would serve as data for all the curves which might hereafter be considered, for either the widening or the contraction of the river at the various points under review. He had dwelt at some length upon these matters, because he deemed it advisable to point out very precisely that before any attempt was made to devise a scheme of regulation, it was indispensable to know within what

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the form here indicated (*Fig. 24*), in which the abscissæ represent the times t, and the ordinates the transverse wetted sections s, at the moments under consideration.

The mean section of the discharge of the flood-tide is given by the formula

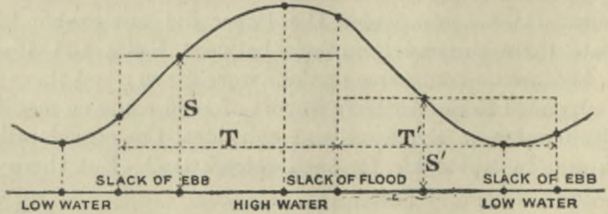
$$S = \int_o^T \frac{s\,dt}{T}$$

and the mean section of the discharge of the ebb-tide, S′, by the formula

$$S' = \int_o^{T'} \frac{s\,dt}{T'}$$

It will be evident from this diagram that throughout the entire range of the river, subject to the play of the ebb- and flood-tides respectively, after low water

Fig. 24.



and after high water the section of the flood-tide discharge is greater than that of the ebb-tide discharge, and that it is therefore the former which, in this case, is the most important to be considered.—H. C. de F.

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limits operations must be confined in order to remain in accord with the hydraulic force of the river, which was itself in turn governed either by the local conditions of its course, or by the expenditure which it was considered might be devoted to it. Turning to the detailed arrangements which had been suggested for the improvement of the Hooghly between Calcutta and Hooghly Point, he was quite in accord with the Author with respect to the proposals of Mr. Lindon Bates for the amelioration of the Atchipur, Moyapur, and Royapur reaches; it was not in the convex parts of the bends that training-works should be formed in tidal rivers, because the available depth in front of the concave part was generally sufficient, and because, moreover, there was a risk of producing erosion in these latter places during the prevalence of floods, and, in consequence, of ultimately accentuating the causes of the divergence between the ebb- and flood-tide currents, both up-stream and down-stream. For the same reason care must be taken, if the projection of the spit at Hooghly Point into the river should be increased, not to press over still farther the current of the flood-tide into the Western Gut, which would have the effect of rendering its curving round towards the north a matter of increased difficulty. But below Brul Point, the left bank of the river made a notable swerve towards the east, and the sandbanks which emerged above low water seemed to indicate that there existed at that point an abnormal excess of available sectional area. If the calculations already referred to should be found to verify this hypothesis, Mr. Bates's plan (*Fig. 22*) seemed in principle to be justified, on condition, however, that the projected reduction in width was confined to the minor bed, and that all the part of the water-way remaining actually subject to tidal influence should be preserved so as not to diminish the volume of the flood-tide, and in consequence the scour of the tidal currents. After all, he did not believe that it would be possible for any length of time to maintain the course of the river in the form in which it now existed between Fulta and Hooghly Point: not only was the outline of this section most defective, but the rivers Damuda and Rupnarayan imported periodically a special disturbance in the channels. From this point of view Mr. Bates's proposal (*Fig. 23*) might be regarded as correct; but, anyhow, it should, in Mr. Crahay de Franchimont's opinion, be completed and improved by the following provisions. In the first place it was imperative that only the smallest possible part of the flood-tide current should be diverted into the affluents. Theoretically these affluents should be done away

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with; but as this was out of the question, the best thing was to endeavour to diminish their effect as far as possible—as the German engineers had done in the case of the Weser, and the French engineers in the Upper Gironde at its confluence with the Dordogne. It would be necessary therefore, if local circumstances would admit of it (as to which he was unable to judge by examination of the plans), to bend round towards their right banks, to the utmost possible extent, the mouths of the rivers Damuda and Rupnarayan in such a way as (1) to oppose the ingress of the flood-tide; (2) to diminish during the prevalence of floods on the one hand, the influence exerted by the Damuda in forcing over the channel towards the left bank of the Hooghly below Fulta Point, and, on the other hand, the tendency shown by the Rupnarayan to create in the vicinity of Mornington Point a channel which, at its union with the channel of the Hooghly, had the effect of directing towards the Western Gut and of maintaining in that position a defective course, and one which rendered the navigation difficult. In a word, it would be expedient to train the outlet channels of the two confluents in general conformity with the accompanying sketch (*Fig. 25*). At the same time, after the mean transverse sections, showing the discharge of the flood- and ebb-tides had been carefully adjusted, by means of the diagrams to which reference had been previously made, it might be possible to proceed to carry out on the left bank beyond Fulta Point the needful diminution in the sectional area, suitable to these reaches; this should, however, be of less magnitude than that indicated by Mr. Bates. The river would in this way be provided with a new left bank more inclined than it was now towards the west, and thus better adapted to direct the ebb-tide currents towards the Western Gut. It would be understood that these works must be carried up above extreme high-water mark. Executed under these conditions, and accompanied by a moderate amount of dredging, intended to hasten the regulation of the channel in the James and Mary reach, these works would, he believed, be productive of good results; but the expense would be very considerable, and he could scarcely estimate it at less than £1,200,000 to £1,400,000. Moreover, it would be increased by the cost of the training-works to be executed farther down the river, between Hooghly Point and Diamond Harbour. He would not venture to pronounce an opinion as to whether the expenditure would be in proportion to the results which would ensue in the improvement of the river and the advantage to

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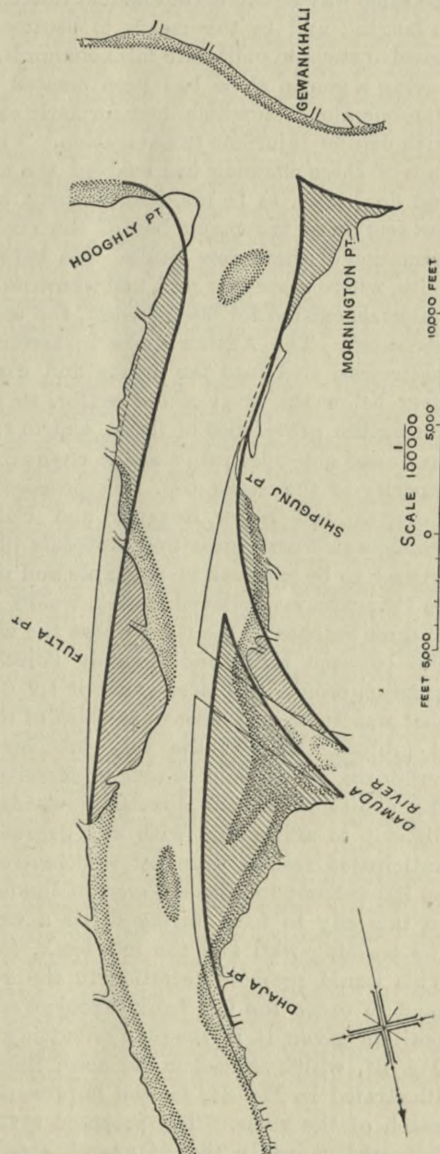
navigation. Like Mr. Robertson, the Author had criticized the use of spurs, in lieu of longitudinal embankments, because the former tended to produce accretion or silting-up in the major bed, which diminished the volume of water introduced by the flood-tides: and this must be avoided at all costs in a river which was maintained solely by the scour of the tides during 8 months of the year. This observation appeared to Mr. Crahay de Franchimont to be most correct, but always with the reservation that here the works to be dealt with were, like those of Mr. Leonard, raised considerably above the level of low-water mark. With spurs raised but slightly above this level, it was nearly always possible to control the amount of silting-up effected, because it was easy to rearrange the faggots of brushwood, and by this means to

Fig. 25.



model the mean transverse section of the river-bed to any extent

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which might be indicated by the calculations. The spurs might in the same way be carried out farther into the river-bed, or be reduced in length; and by this means it became possible by gradual progressive steps to obliterate false channels. In this way new banks having a gentle slope had been created at several points on the Garonne, alongside which there formerly existed secondary channels, with depths injurious to navigation. The almost total disappearance of these channels had enabled the main channels of the ebb- and flood-tides to be reunited, without any sensible alteration of the section of the major bed of the river in consequence of the formation of these new banks. He believed that in the Ganges delta, where stone was rare, and where on the other hand abundant materials existed for fascine-work, the use of this latter should be advocated. The Author spoke in favour of the use of fascine-mattresses, tied into the banks and directed obliquely into the river below the level of low water, so as to direct the currents during the prevalence of floods, and to reunite the currents of the flood- and ebb-tides into a single channel, without diminishing the capacity of the major bed. He proposed to apply this system at Moyapur, and below Royapur and Fulta Point. This system, which was based upon the proposals of Mr. Leonard (*Fig. 19*), seemed to be rational in principle and prudent; and Mr. Crahay de Franchimont believed that it would bring about good results in those reaches of the river where the widths were not too great. But between Fulta and Hooghly Points, where the mattresses in question would be placed at about 1,970 feet from the left bank, that was to say, at about one-third of the width of the river, was it probable that at the very low level at which they would terminate, they would be able to exercise an effective control upon the ebb-tide channel directed towards this bank? It seemed difficult to affirm this with any degree of certainty; and if the anticipated results were not sufficiently realized, there would be an inducement to raise the crest of the mattress training-wall, and in this way to form during floods a vast settling-basin between the training-wall and the left bank, for the deposition of silt. This would promote accretion in the river, which would finally tend to cause the left bank to project considerably in front of the position given it in the plan of cutting off Fulta Point, shown in *Fig. 25*, which seemed in its main lines more suitable than that illustrated in *Fig. 21*, for the improvement of this very defective reach of the river. The proposed system of training-walls thus appeared more in the nature of a palliative measure than an ordinary method of regulation; and he believed that, in order to furnish good results, it would have to be accompanied by an important amount of dredging. Mr. Crahay de Franchimont.

II. From the navigation point of view, it was necessary to lay down and to obtain as regular and as continuous a channel as possible in the river, and one of a size sufficient to enable two large vessels to pass one another in safety with a sufficient amount of way on them to prevent loss of steering-power. The depth would at the outset be limited by the hydraulic power of the river, after its regulation. As soon, therefore, as the amended sections had been settled for the various points, and when, in accordance with these sections, the two banks of the minor bed, which ought in the same way as the channel itself to be as regular and continuous as possible, had been traced, the only means available for deepening the river in certain reaches, or of removing any deposits which might have been accidentally accumulated during floods, would be by dredging. There was, however, a matter to which attention ought to be directed, in view of the great distance of Calcutta from the sea, and this was the nature of the "sailing regulations" actually adopted for ships in ascending or descending the Hooghly. Were these regulations in perfect accord with the law governing the propagation of the tides? He asked this question because it was one which he had had to solve in the case of the Gironde, and because it was intimately connected with the final depth which ought to be provided in each point of the river whose rectification was being considered. The limits imposed on these remarks would not permit him to enter here into further details; but, in order to give his precise views, he forwarded with his communication a Note[1] respecting the employment of graphic track-charts for the various tidal coefficients which were found to prevail in the Gironde, as the results of the observations of tides and slacks, and of soundings carried out in the river. This chart had been in use at the port of Bordeaux since the year 1896, where it had rendered great service, and had been the means of laying down upon a scientific basis the rules relating to the passage of ships up and down the river, which were formerly entirely empirical. It would be very interesting if analogous track-charts could be constructed for the Hooghly, and be brought to the notice of engineers who might be occupied with its improvement. To sum up his conclusions: it appeared to him that, in order to formulate a well-informed

[1] "Note on the Passage of Vessels in a Tidal River of Great Length." Minutes of Proceedings Inst. C.E., vol. clx.

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opinion respecting the improvement of the Hooghly, it would be necessary to be furnished with several essential particulars. The first point to be decided was the depth below sea-level needed at each point in the river for the largest ships bound to visit the port of Calcutta: this should be arrived at after taking into consideration, not only the longitudinal section of the river and the course of the navigable channel, but also the conditions which governed the progress of vessels and the tidal regime. Graphic route-charts would furnish the rigorous solution of this problem. The depths thus laid down h_1, h_2, h_3, etc. (*Figs. 26*), compared with the heights H_1, H_2, H_3, etc., above low-water mark, corresponding with the mean sections representing normal discharges S_1, S_2, S_3, etc., which would be calculated in the manner already described, would enable the limits of the minor bed l_1, l_2, l_3, etc., to be computed for each locality, with sufficient accuracy, which it would be desirable to obtain after the completion of the regulation-works. This minor bed should naturally follow the channel itself, and, like it, be continuous and regular throughout, in order to avoid all tendency to weaken the tidal wave and the volume of the flood-tide above the section under consideration: nor should it be forgotten, all other things being equal, that an enlargement should take place at the bends, and a contraction in the channels between one bend and another, in order to secure a single channel for both flood and ebb. These essential principles would lead to the undertaking of the entire study of the tidal river, between the limit of the tidal range and the estuary, all the parts of such a river being interdependent. From this special point of view, it might not be amiss to carry the study of projected improvements above Calcutta, inasmuch as between this city and Nadia the wave of high water underwent an abnormal depression of 23·6 inches, whereas the reverse should be the case. This would imply that there must be some palpable irregularity in the propagation of the flood-tide in this district, which resulted in the loss by the port of Calcutta of a volume of tidal water, whose scour would be useful for its maintenance. Only after the determination of the data to which he had just drawn attention—which would be of great interest—and after the rational form to be given to the course of the Hooghly so as to promote the interests of its maintenance and its navigation had been thus settled, would it be possible to approach the question of the works which, having regard to the possible outlay, would best accord with the indications of theory. As far as could be judged, these works would generally be of minor importance, except in the district comprised between Fulta and Hooghly Point, where the course of the river was

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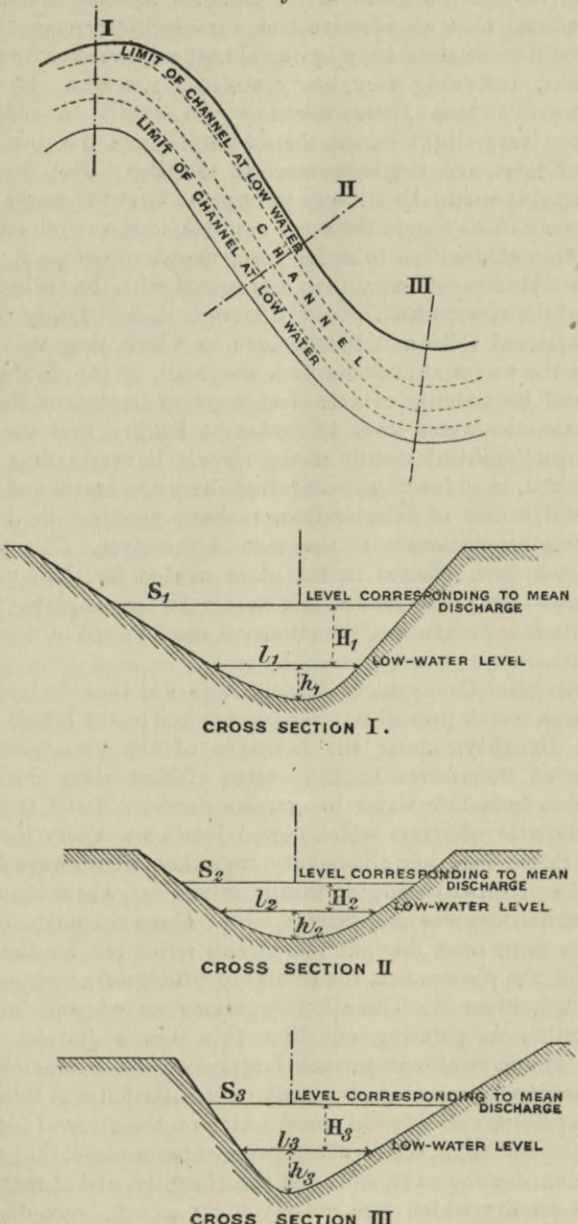
Figs. 26.



Mr. Crahay de Franchimont. so defective, and the action of the Damuda and the Rupnarayan so prejudicial, that an effective and durable improvement of this reach could be attained only by the almost entire reconstruction of the banks, involving very heavy and costly works. It seemed also probable that these works would result in modifying only to a very slight extent the amplitude and the duration of the local tides, and the importance of the bore. But, under any conditions, it would be illusory to suppose that the works undertaken, even if they were the most suitable to the requirements of the river, would suffice to secure permanent improvement. These works could never do more than correspond with the ordinary condition of the river, which would be more or less violently modified by exceptional tides and by the bore to which they would give rise, by the waves of cyclones, and, above all, by the floods in the river and its tributaries: the last were so important that they raised the low-water level 12 inches at Khijiri, that was to say, at the geographical mouth of the river. It would thus always be essential, in order to guard against these accidental and almost periodical causes of deterioration, to have recourse to dredging on a scale proportionate to the size of the river. The progress which had been effected in the plant needed for these purposes was great enough to render it possible to contemplate, without any serious apprehension, the extensive employment of this system of improvement.

Mr. Crugnola. Mr. GAETANO CRUGNOLA, of Teramo, remarked that the interesting conditions which prevailed in the estuary and in the lowest portion of the Hooghly, under the influence of the variations which manifested themselves in the waters of that river during the transition from low water to extreme floods, differed from those characteristic of rivers which flowed into a sea where there were heavy tides; and they differed also from those which were found to prevail in rivers discharging into an inland sea, where the range of tidal oscillations was hardly perceptible. These circumstances could scarcely have been brought into strong relief but for the minute study of the phenomena, the results of which were represented in Figs. 3–6, Plate 2. These investigations served well to justify the Author in pointing out that this was a distinct type of river, which, while it partook largely of the characteristics of tideless rivers, presented also many of the attributes of tidal rivers. It was precisely to this reciprocal action on the river of high floods and powerful tides, whose effects were superimposed, that the good conditions for the navigability of the Hooghly, and of that portion of the estuary which was nearest to its mouth, were due. This was contrary to the opinion of Mr. Longridge, who had had too great an interest in bringing out strongly the superiority of the Mutla branch; the results demonstrated this point clearly. As a matter of fact, the minimum depth in the channel of the estuary of the Hooghly was, according to the Author, "15 feet at the lowest low-water of the dry season," and "29 feet at high water of ordinary spring-tides." In a river of this kind where, in spite of the influence of the tide, there were numerous deposits of sand along the bed of the estuary, it was very important to study the movements of these deposits, which could not fail to occur, and which must be produced in a way quite different from the movement in rivers not subject to tidal influences. This study had still to be undertaken for the Hooghly, and it might be of great utility in the application of the methods destined to maintain the depths needed for navigation. All the data with respect to "Channels and their Changes in the River Hooghly" were well set forth in the Paper; but, as touching the James and Mary shoal, it seemed to Mr. Crugnola that the rivers Damuda and Rupnarayan, which discharged into the Hooghly in this vicinity, and whose combined volume was greater than that of the latter, must have a considerable influence. The Author brought clearly into evidence all that related to the Damuda, but passed somewhat hastily over the facts with respect to the Rupnarayan; whereas it would have been interesting to have these results equally fully, because it was extremely probable that the eddies produced by the discharge of its waters, and of the material which they carried down, had likewise an influence on the phenomena which manifested themselves at the down-stream end of the James and Mary reach. In every case the action of the currents contributed to the maintenance of the depth between Hooghly Point and Diamond Harbour, in spite of the tides which extended over two-thirds of the year. The Author limited the works intended to increase the depth to six points, more especially the Moyapur, Royapur, and James and Mary crossings, because all the other obstructions were obviously defects due to the physical characteristics of the Hooghly. But Mr. Crugnola thought it was possible to go still further with the deductions, and to predict with certainty that even the dredging operations carried out to increase the available depth in these three places would produce a useful effect only in so far as they might be periodically repeated; because the shoals would always have a tendency to re-form in the same localities. It was a question of money; nevertheless the expenditure required by works of this nature was largely justified by the advantages which the Author set

Mr. Crugnola. forth in the last paragraph of the section of the Paper headed "Navigable Condition of the River Hooghly." Turning to the examination of the methods proposed for increasing the navigable depth of the Hooghly, it was certain that the Damuda, by its confluence with the Hooghly, compelled its principal current to skirt along the left bank from Fulta as far as Nurpur Point, and that, by turning aside the waters of the Damuda, the Hooghly might, in consequence of the influence of Fulta Point, approach the right bank. The Author objected that "the main current of the freshets and ebb-tide, after being directed against the right bank below the present mouth of the Damuda, would again be diverted across the river towards Nurpur by the projection of Shipgunj Point;" but this was not a sufficient reason for abandoning this mode of improvement, because it would not be difficult to regulate the projection so as to render its action less perceptible, or even to neutralize it entirely. Then the main current would not be forced over from the right bank to the left, and would continue its course along the right bank, and pass ultimately into the Western Gut. The question should, however, be considered also from the point of view of the cost of such a diversion, and of the difficulty which might be experienced in maintaining the flow of the Damuda along its new course: concerning this the Paper did not contain the requisite information to afford a reply. Again, the diversion of the river would deprive the reach down-stream of Fulta Point of the scour of the volume of fresh water from this river, the action of which was doubtless considerable. In regard to Mr. Leonard's proposal to divert the Rupnarayan into the Haldia, he was in accord with the Author that it would diminish the scouring efficiency of the freshets and tides in the Hooghly, and along the reach between its mouth and the outlet of the Haldia. The other improvement proposed—the impounding for a time of the surplus water of high floods of the Damuda till its inadequate channel could receive them—would perhaps be advantageous, because it would augment the scouring efficiency of the freshets through the James and Mary reach. But its application could not be advocated without complete knowledge of the locality. The training-works proposed by Mr. Leonard for lowering shoals in the Hooghly were, to Mr. Crugnola's mind, of doubtful efficacy. Longitudinal training-walls were preferable to spurs, because the latter altered the conditions of the river, and it was not easy to foresee in which direction the alterations would occur in a river governed by such an exceptional combination of physical conditions. In general it was essential to respect the tidal capacity of the river; and it might be very risky to offer the slightest impediment to the flood-tide up the Hooghly, where the tidal water was the sole scouring agency for the maintenance of the river during two-thirds of the year. The results already obtained from the executed works were very limited, and it was not even certain that where they seemed to have had good effects these should be imputed to them. There was no doubt that in some places they had done harm, as pointed out in the Paper. Such a means of improvement was always dangerous in application, and should be resorted to only with the greatest circumspection and in special cases. The proposed fascine-mattress training-walls seemed to be an acceptable improvement, if the advantages claimed at p. 39 could be admitted—which was not quite proved, because the changes in the bed of the river, according to the seasons, could not be foretold, and might occur in a very different manner from what was expected. Therefore he was of opinion that the best improvement might be the combination of fascine-mattress training-works with continuous dredging on a large scale. With reference to the scheme propounded by Mr. Lindon W. Bates, it was true that each enlargement in a river was a source of trouble; but the regulation of the width was not always successful in preventing the formation of shoals and bars and increasing the navigable depth, when it did not remove their cause, especially in a river of such exceptional character as the Hooghly. The works proposed by Mr. Bates for improving the Moyapur and Royapur reaches, and the removal of Fulta Point would not improve the navigable condition of the river, for reasons given by the Author, with which Mr. Crugnola quite agreed. Mr. Crugnola.

Mr. T. S. Ellis, of Gloucester, had recently restated[1] certain views on river-courses which he had first put into print 21 years earlier, namely, that the disposition of a river was to pursue a straight course, and that in alluvial soil the usual diverting influence causing a curve was a tributary or affluent stream which had weakened the bank by breaking its continuity, and, by keeping open a channel from its point of influx towards the sea, had prevented the consolidation of deposit; while similar deposit on the opposite side, having no such channel through it, remained and consolidated. At Hooghly Point, as shown in the chart of 1900–1 (Fig. 16, Plate 4), no tributary appeared between it and Fulta, and the river had gone over towards the Rupnarayan, but not altogether, for there was still a channel on the eastern side. Mr. Ellis.

[1] *The Geological Magazine*, vol. x. (1903), p. 350.

Mr. Ellis. This must be due to some diverting influence; not, indeed, enough to divide the river equally and leave an island, but enough to keep open a channel. Even if no tributary were seen on the other charts, he would feel sure of the existence of at least one. The channel was not in the line of the principal stream, kept open near the right bank by the influx of two large rivers. It was not in the line of the tide, directed onwards by the straight reach from Diamond Harbour. There was no apparent reason for it, unless it were to carry the water derived from tributaries, such as Anchoring Creek (Fig. 13, Plate 4) and those near to it. If these were intercepted, united, and brought out opposite Luff Point, so as to leave an absolutely unbroken line from Fulta to Hooghly Point, the channel, no longer needed, would cease to exist. From this point of view much might be said as regarded the whole line of river, but the smaller tributaries had evidently been regarded by the chart-makers as immaterial. In this respect the charts did not accord one with another. He was confident, however, that a good map would serve to show that the course of the Hooghly had largely been determined by the tributary streams, and to support his contention that the tributaries must be controlled and directed by the engineer who sought to regulate the course of the river. By this means he could best fix the low-water channels which, at all times, were the deep-water channels. Mr. Ellis believed that if all tributaries, however small, were carried out into the river (either separately or by the union of two or more), to the marginal line of a low-water channel, actual or intended, such channel, bounded by this line, would be permanent. He assumed this to be done by submerged dykes, and saw no reason why they should not be at right-angles to the shore. He was confident that careful study of the tributaries of this river would disclose something to explain the deviations, especially the great curve between Hooghly Point and Haldia Point.

Professor Gaudard. Professor J. Gaudard, of Lausanne, remarked that the Hooghly exhibited the singular feature of being at the same time a deltaic branch of the Ganges and a river fed by independent tributaries. The fresh waters charged with alluvium, which flowed down during the 4 months of the rainy season, as also those derived from the Ganges, became almost exhausted during the rest of the year, apart from the filtration through the bed, in such a way that during this latter period there remained little but the tidal waters. Towards the sea the river discharged into an estuary abounding with islands and sandbanks, where the navigable channel was continually shifting while retaining sufficient depth

Professor Gaudard.

of water. The Paper was essentially confined to the question of the rectification of three points of the contracted portion of the river-bed above the estuary. The windings of a river running through alluvial soil were a natural phenomenon, arising from the equilibrium between the erosive force and the silting tendency of the waters. Moreover, the removal of bends in the course must be resorted to with caution. It was clear that the first aim of the water was to follow the line of slope of the country; but if the river caused erosion and hollowed out its bed, it created a counterslope, where it deposited the materials, and the current deviated from its regular course to get round this obstacle. In this way sharp bends were produced, also deviations and changes in the outlets, in accordance with the volume of the waters rendered more or less capable of carrying along their load of drift. In a winding bed, the strong current, and consequently the deep and navigable channel, was carried over to the concave side by centrifugal force; it there became concentrated and hollowed out its bed; whereas, in the intermediate reaches, it spread, its speed slackened, and silt was deposited. The channel was therefore more winding than the actual course of the river. The deposits accumulated chiefly on the convex sides of the bends, but they were gradually removed by the water; and, in order to facilitate this action, it was advantageous to narrow the river artificially in the reaches between the bends. In the Garonne, Mr. Fargue had brought the training-walls to within 492 feet of each other in the reaches between the bends, the mean width being about 656 feet at the apexes of the curves, in such a way that the width varied periodically and gradually. Besides his observations on this river, Mr. Fargue had also carried out a series of trials with a small artificial river,[1] and he had ascertained that the centres of the pools, or deep portions of the channel, did not coincide with the apexes of the concave parts, but, as the result of inertia, were moved a little lower down-stream. In the same way the greatest projection of the alluvial deposits was found down-stream from the centre of the convex bends. This "law of divergence" prevailed also in the case of the shallows in the channel, which likewise occurred down-stream of the points of transition from convex to concave bends. As every sudden change in the curvature of the longitudinal axis of the river was accompanied by a sudden change in depth, Mr. Fargue had insisted upon the importance of giving gradual curves to the training-

[1] *Annales des Ponts et Chaussées*, 7th series, vol. vii. (1894), p. 426.

Professor Gaudard. works of rivers, and he had proposed that for joining together the bends, curves of the lemniscate or sinusoid class should be employed. From the dynamic point of view, too, the curvature of the trajectory of a moving mass composed of sand and water must not be overlooked, in respect of the action exerted against the bank and the reaction of the latter. It was this reaction which determined the transverse movement of the gravel, and which contributed towards causing the separation between the water and the solid matters—which, in fact, excavated the concave side and filled up the convex side of the bend. If a portion of a river subjected to the action of an alternating tidal current were considered, such as the Hooghly, it would be seen that the digressions of the ebb-tide channel would be produced in the down-stream direction, while those of the flood-tide would take place up-stream; and it was this which caused the divergence between these two channels. They coincided well in the bends, inasmuch as both tended to press against the concave bank; but at changes of curvature, or in the straight parts of the river, if its course widened at all at these points, the two channels found room to separate and become distinct. In order to induce them to come together again, it would suffice to diminish the width of the bed in the intermediate reaches, as proposed by the Author. The effect would be to diminish the difference between the ebb- and flood-tide channels, and to lower the deposits at the axial crossings of the river, thanks to the force of the flood-tide, which stirred up the sand, and to the force of the ebb-tide, which in its descent carried it away. Whilst the ebb-tide was slower and more continuous, since it was controlled by a constant head of water up the river, the flood-tide had an undulatory movement. At the outset it was strongly impelled by a head of water in the sea; but as it was gradually propagated up the river, it continued to rise, while the sea-level fell, and it possessed only an impulsive movement due to its acquired speed. It was thus essentially variable; it attained a maximum, and at the height of its action must possess great power. In attempting to pass up a bed not adapted to its impulsive force, it proceeded gropingly and tended to push out blind channels, wherein the water assumed a premature back-flow. Coming into collision with the descending current, which was more sustained and was intensified by the freshets, it remained more superficial, and ultimately became extinct. It was essential to remove as far as possible the obstacles to its onward progress; and this was what the Author proposed to do by training-works only alongside the bank skirted by the ebb-tide, as shown in *Fig. 20*, keeping the training-wall at a low level in order not to decrease the tidal capacity of the river. The James and Mary reach was subjected to much more complex conditions; the Damuda conveyed into it its transverse current and an excess of sediment, while lower down Hooghly Point formed a sharp elbow opposite the Rupnarayan. The effect of the current of the Damuda was to keep the ebb-tide channel close against the left bank towards Fulta Point, and it naturally followed the consecutive concave bend; whereas the flood-tide, arriving from the opposite direction against the mouth of the Rupnarayan, with difficulty turned aside and followed the right bank of the Hooghly; and a regular sandbank separated the two guts. Following out his principle of forcing the ebb-tide channel into that occupied by the flood-tide, the Author proposed to erect a low training-wall starting from Fulta Point and extending onwards until opposite Hooghly Point (*Fig. 21*); and it was to be hoped that this work would fulfil its object, and that the tide would scour away with sufficient rapidity the sandy obstructions of the Damuda. Opposite the mouth of the Rupnarayan there was no want of depth of water; but there would always be a difficulty in the navigation of this sharp elbow in presence of the conflicting currents. While congratulating the Author on the perspicacity of his Paper and on the valuable improvements which he proposed, it appeared to Professor Gaudard that it would be advisable to consider more fully the relative turbidity of the waters of the ebb- and flood-tides. The tidal wave, before beginning to ascend the river, passed over the muddy shores of the estuary; it might, therefore, stir them up more or less, move them, and transport some of the alluvial matter back to its former resting-place. He supposed, however, that this action was very limited, and that, on the whole, the incoming tidal wave must be much clearer than the waters of the affluents coming from the mountains. When the discharge of these latter ceased and no longer impeded the incursion of the tide, this tidal wave became more abundant, in such a way as to take possession of the space thus given up to it, at any rate in the case of the Damuda and the Rupnarayan, which were in proximity to the estuary. And these flood-tide waters which passed up-stream to redescend immediately with the ebb, augmented the volume of the latter and increased its scouring power. The waters coming from the Ganges, having been drawn off from the higher layers of this river during its overflow in floods, were probably less turbid or contained lighter silt than those of the Damuda. On the whole he was led to believe that the navigable course of the Hooghly

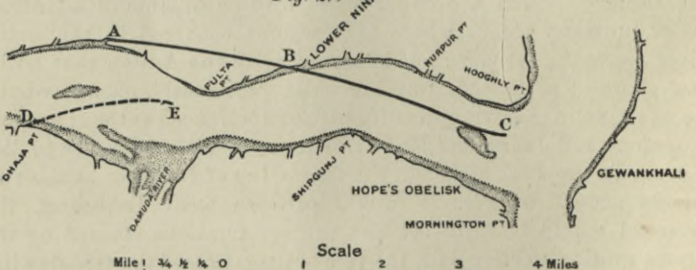
Professor Gaudard.

Professor Gaudard. during the dry season must be better and freer from sand than it was during the rainy season, or at the end of it; if the ebb-tide had diminished, the flood-tide had increased. On the other hand, during the prevalence of floods, the ebb-tide became more voluminous and powerful, but it was also fully charged with alluvial material which must be carried down to the sea. It took part in the sweeping out of the channel, but it also rendered it foul. He could not, therefore, regard the so-called cleansing of the bed by the floods of the Damuda as being advantageous for the James and Mary reach; and it seemed to him that it would be better if both this river and the Rupnarayan had no existence. Supposing the Damuda to be increased indefinitely in size until it invaded the whole bed of the Hooghly, drove back entirely the flow of the sea, obstructed with its sand-beds not only the James and Mary reach but also the whole river in the down-stream direction, as well as the estuary itself; did it not appear evident that, on a small scale, analogous injurious effects were actually produced by the existing river? The current of the Rupnarayan, thrusting itself straight to the east of the Hooghly, below Hooghly Point, but intersecting transversely the down-stream current from the north, must inevitably result in abruptly checking this latter by causing the level of its waters to be reversed, and must consequently induce and increase the sandy deposits in the James and Mary reach. The Damuda contributed extensively to these deposits, and, at the same time, encountering the current nearly at right-angles, it likewise caused the waters to flow back, and was partly responsible for the sedimentary obstruction retained between Dhaja Flat and Fulta Sand. It would therefore appear to be preferable that there should be an increase of flood-tide which might fill the river at this point and return with the ebb. Since, however, it was not possible on the score of expense to divert the Damuda and the Rupnarayan down to the Haldia, he was of the same opinion as the Author, that nothing could be done for the improvement of the James and Mary reach beyond bringing back the ebb-tide channel into that of the flood-tide in the Western Gut, by the construction of a low training-wall in such a way as to increase, by means of the improvement of this gut, the facility of access for the tide, which would then disperse the alluvial matters in the eddies and in the large volume of water. There would then remain the idea of forming a cut across the elbow at Hooghly Point, as proposed by Mr. Brooks (*Fig. 17*), which would present a seductive appearance as a means of diminishing the conflict of the currents and of facilitating the inflow of the tidal wave—if the work were not much too costly, and if it were possible to make the cut start considerably higher up. It should be combined, by means of a barrage, with a diversion of the mouth of the Damuda into the ancient arm of the Hooghly, so that in conjunction with the Rupnarayan it might discharge lower down, and in a better direction beyond this new cut. Professor Gaudard.

Mr. T. W. KEELE, of Sydney, N.S.W., considered that the Author had contributed a Paper of much interest and value to those concerned with the improvement of navigable rivers. After carefully studying the Paper, he thought it would be useless to attempt to carry out, at a reasonable cost, any works for the purpose of confining the channel of the Hooghly, or fixing it in one position through the estuary, in view of its great extent, and the shifting character of its shoals and sandbanks. It would appear, however, that during the dry seasons, when the discharge of upland water was inconsiderable, a suction dredger of the self-propelling, hopper type, designed specially for working on exposed river-bars, would be found exceedingly useful in maintaining the channel through the estuary. Such a dredger would also be capable of affording relief in many places where obstructions occurred in the main river above the estuary; but he agreed with the Author that nothing short of permanent training-walls, judiciously placed, would be effective in removing the difficulties experienced at the Moyapur, Royapur, and James and Mary crossings. With reference to Mr. Leonard's proposal, although the narrowing of the river at the two places shown in *Fig. 18* would produce local deepening, the channel would be throttled, and the reclamations effected by the spurs would interfere with the free propagation of the tide flowing up the river. The treatment shown in *Fig. 19* would improve the course of the river; but the reclamations were objectionable, and the works would not remove the Muckraputty shoal, at the lower end of the reach, caused by the divergence of the flood- and ebb-tide currents. If the Rupnarayan did not discharge into the Hooghly where it did now, and if a cut were made in the position shown in *Fig. 17*, as proposed by Mr. Brooks, the bend would silt up; but, under present conditions, unless a dam were placed across the river below Nurpur, high enough to divert all the water of the main river through the cut, the proposal would certainly end in failure if carried out. The cost of such a dam, added to that of the cutting, would, of course, be prohibitive. In his opinion the scheme proposed by Mr. Lindon W. Bates for the Mr. Keele.

Mr. Keele. improvement of the Moyapur and Royapur reaches, by the construction of walls carried up above the highest water-level, and reclaiming the sandbanks at Atchipur, Hiragunj. and Brul Points (*Fig. 22*), would be an unnecessary expenditure of money, inasmuch as it would not effect the desired result of improving the crossings, but would increase the depth along the concave banks where it was unnecessary. These banks would also be eroded and cut back until the channel of the river at these places had accommodated itself to the original cross-sectional area, and sandbanks would be found outside the walls, on the convex side, somewhat similar to those at present existing. The removal of Fulta Point in the manner shown in *Fig. 23*, would not permanently improve the course of the river at that place, caused under existing conditions by the conflict of the currents resulting from the discharge of the Damuda and the Rupnarayan into the main river; but even if it did, it would have no appreciable effect in removing the difficulty caused by the Muckraputty shoal; indeed, it might be expected to extend farther up the middle of the river, and ultimately to form a worse obstruction than it was at present. The extensive walls

Fig. 27.

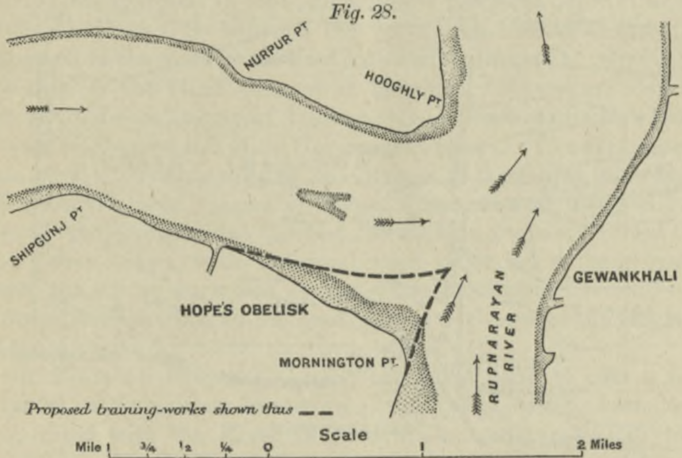


and reclamation-works on the convex bank, were unnecessary for the regulation of the channel, as the descending current would hug the concave bank; and accretion of the opposite shore would take place naturally without the aid of any artificial works. He agreed with the Author in his treatment of the cases under discussion, as being in accordance with correct principles. In the consideration of the problem to be solved, for the improvement of that portion of the river between Fulta and Hooghly Point, the re-entering angle in the left bank made by Fulta Point appeared to be unnatural, and to require amendment by the removal of that portion of the Point outside the thick black line A B shown in *Fig. 27*, and the construction of a training-wall, B C, along the prolongation of the curve, shown by black lines, which would be coincident with the direction of the lower portion of the wall proposed by the Author in *Fig. 21.* If the Damuda did not discharge into the Hooghly where it now did, this method of regulating the channel would no doubt be very effective although costly; but, on consideration of the matter, and comparing the charts, it was noticeable that Fulta Point and Hooghly Point had been maintained in their respective positions with little if any variation over a long term of years. Were it not for the peculiar action set up by the conflict of the currents, caused by the enormous discharge of the Damuda and the Rupnarayan into the main river, which was stated to be approximately equal to the discharge of the latter above its junction with the Damuda, Fulta Point and Hooghly Point would no doubt have been cut back by the endeavour of the river to straighten itself. It would therefore be useless to attempt the removal of Fulta Point, otherwise it would have a tendency to re-form, which would necessitate the construction of a spur, D E, (*Fig. 27*) from the right bank at Dhaja Point, the lining of the concave bank from A to B, and the raising of the training-wall B C probably to high-water level for the upper portion of its length. The spur D E would require to be of a very substantial character, and before its completion to the full length would probably obviate much expense in the excavation or dredging work at Fulta Point. The scheme would, he considered, be very effective in removing the difficulties of navigation in this portion of the river; but its cost would be much greater than that of the plan proposed by the Author, which should be quite sufficient for the purpose at present required. Mr. Keele.

Mr. J. C. LARMINIE's first impression on perusing the Paper had been one of surprise at the comparatively insignificant changes which had taken place in the general regime of the Hooghly during past years; which was the more remarkable in view of the heavy flood-discharges, and the daily scour due to a considerable tidal range. In this connection it would have been of interest had a few figures been given showing the velocity of the river in different reaches under varying conditions due to freshets and tidal flow; it was scarcely possible to calculate them from the tidal diagrams and the longitudinal section of the river. In fact, to any one who had to deal with other large Indian rivers—the Godavari, for example—the Hooghly would appear to have been an extremely well-behaved river; and to account for this fact, he could only suppose that, although the flood-waters, like those of Mr. Larminie.

Mr. Larminie. most Indian rivers, were heavily laden with silt, the amount of sand carried down was after all not very large. In his experience, and notably in the case of the Godavari River, changes were perpetually taking place in the direction and depth of the channels and in the positions and formation of shoals and islands: and of greatest concern to the engineers in charge was the wholesale destruction of the river-margins, involving, as it often did, heavy expenditure on carrying canal-diversions—which in the Godavari and Kistna deltas invariably skirted the river-margins—perhaps ½ mile inward. There could be no doubt that these erratic changes, caused by what were locally termed "river-sets," were entirely due to the travel down the river of large quantities of sand. The normal section of water-way had to be maintained somehow, and once this became encroached on by the formation of shoals, which invariably extended themselves down-stream, destruction of the margin began, usually some distance down-stream of the obstruction. Occasionally protective works in the shape of groynes, spurs, or revetments, might avert much damage until the "set" had worked down and the danger had passed; but, as a general rule, this did not occur until much damage had been done and expenditure on canal-diversions incurred. In fact, once a determined set began, it was hopeless fighting it, except at prohibitive cost. In many instances large sums had been expended in fruitless struggles with the river. In the Hooghly there must, of course, be some travel of sand sufficient to account for the minor accretions in the upper reaches of the river, as at Hiragunj Point and Brul Sand. But in regard to the chief and most dangerous obstruction to navigation—the James and Mary shoal—it would seem probable that the main cause of the evil was sand brought down by the Damuda and the Rupnarayan and deposited in that reach by the complex currents there prevailing. The tendency of the flood-tide passing round Hooghly Point would be to divert much of the Rupnarayan sand and to deposit it on the James and Mary shoal; and from this point of view the problem would be to devise some training-works which would counteract this tendency, and enable the Rupnarayan flood-water to neutralize, to some extent, at all events, the diversion up-stream of this sand by the flood-tide. *Fig. 28* illustrated a suggestion for such a work. There had been a tendency, as shown by the most recent survey, for a sand accretion to form along Mornington Point. This would form a base for two curved training-jetties to start from, meeting at a point opposite Hooghly Point, say at one-fourth to one-third of the width of the Hooghly from its right margin. The jetty on the Hooghly side would tend to divert the freshets and ebb-tide in a direction opposed to the deposit of sand on the James and Mary shoal; while at the same time it would exert a scouring influence on the right side of that shoal, though to less extent than the long training-jetty from Fulta Point proposed by the Author. The training-jetty in continuation of the left margin of the Rupnarayan would also tend to direct the outflow of that river towards the Gewankhali shore, and combining with the Hooghly down-flow, at the apex of the two jetties, the resultant flow would then be headed fairly down-stream. With Mornington Point and the mouth of the Rupnarayan in their present state, it seemed possible that, under certain conditions of flood and tide, sand and overflow from the Rupnarayan might Mr. Larminie.

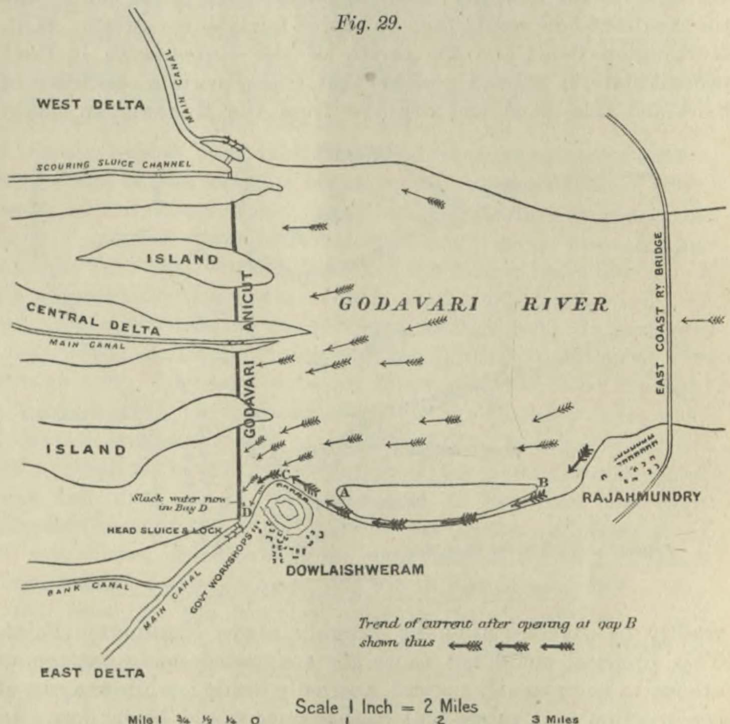
Fig. 28.



readily be diverted into the Hooghly above Mornington Point. This proposal could not cause any counterbalancing damage, as others, to be presently noticed, assuredly would; while the cost of construction and subsequent maintenance would be far less. In regard to the various proposals made from time to time for the improvement of the Hooghly, it appeared that the chief desideratum would be the improvement of the river between Calcutta and Hooghly Point, or perhaps as far as Diamond Harbour. Below that, so extensive an estuary, swept by strong tidal currents, causing the constant shifting of the shoals, was outside the scope of practical engineering; and all that could be done was to watch carefully the changes in the channels. In common with many other Indian projects, the Hooghly appeared to have been the

Mr. Larminie. subject of successive reports and proposals during many years. The difficulty of the question, and the divergence of opinion, had no doubt prevented anything from being done. The diversion of rivers, and the improvement of their courses by cuts across projections, were theoretically fascinating; but in deep, rapid streams flowing through alluvial soil it was not often successful. Sir Arthur Cotton had once attempted the improvement of a branch of the Godavari, by a cut through a point not unlike

Fig. 29.



Hooghly Point. Mr. Bates's proposals were pertinently disposed of by the Author; but might not similar exception be taken to the Author's own proposals, *e.g.*, the training-jetties in the Moyapur and Royapur reaches? These would, no doubt, improve the crossovers, but it seemed fairly certain that they would cause considerable erosion of the opposite concave bends. The long jetty below Fulta Point would have a similar effect; and unless Mornington Point could be efficiently maintained, a whirlpool action

Mr. Larminie.

might be expected to arise around the mouth of the Rupnarayan, followed by a scooping out of the Gewankhali margin. The protective foundation for such a jetty in a deep tidal reach would, moreover, be difficult and costly. A striking instance of how an apparently trifling alteration in the regime of a large river at one point might have injurious effects lower down, was afforded by the reach of the Godavari for about 4 miles above the Anicut, which was illustrated by *Fig. 29.* Up to about the year 1896 the long island A B was joined to the mainland at B, a deep blind channel existing all along A B, between it and the mainland. So far, the main flow of the river followed the direction shown by the light arrows, and, heading straight for the Dowlaishweram (the left) branch of the Anicut, maintained a fairly clear approach to that branch, and a sufficient depth of water along the bay C D, between the projecting hill at C and the approach to the main canal-head lock and sluices at D. Gradually the head of the blind channel at B opened, followed ere long by the gradual shoaling up of the bay C D in front of the Dowlaishweram workshops and other Government offices. The explanation was simple. The opening of the channel A B enabled it to draw off a considerable volume of water, which flowed along till it met the projecting hill at C, which, acting as a groyne, diverted the flow across stream, with the usual slack water below the groyne: hence the silting-up, which up to 1898 had threatened seriously to obstruct the approach to the head lock and sluices at the left end of the Anicut.

Sir Bradford Leslie.

Sir Bradford Leslie, K.C.I.E., felt called upon to offer a few remarks on the matters treated of in the Paper, having been long acquainted with the River Hooghly. The configuration of this and other rivers in Lower Bengal depended upon the existence of the hard clay formation at varying depths. This clay yielded very slowly to the erosive action of the tidal current, and where it rose above low-water level it fixed the topographical features of the river. The clay bed was not persistent, and over large areas it was wanting altogether. The presence of the clay at Kidderpur had enabled the foundations of the entrance-locks to be got in without cofferdams; while a little in the rear the dock-walls had had to be founded practically in a quicksand. For this reason any proposal to tamper with the hard clay banks of the river, like that of Mr. Bates for cutting away the projection of Fulta Point, would be extremely rash, and might cause a wholesale diversion of the river into the soft ground behind. The bends of the river were useful in checking the momentum of the ebb-tide. If the river

Sir Bradford Leslie.

could be straightened, the tide would ebb out so low that no ships could be berthed at the jetties in the Port of Calcutta, while the silting-up of the sandheads would become much worse from the deposition of the coarser sand carried by the increased velocity of the tide. For these reasons any attempt to dig new channels, or to make short cuts for the Hooghly, could not be too strongly deprecated. He had no doubt that the existing channels might be improved by diverting the ebb-tide into the flood-channels as proposed by the Author; but he apprehended that whatever measure of success was attained in this direction must inevitably result in the silting-up of the disused ebb-channels, not only below low water but also above, thereby reducing the volume of tidal flow available for scour. The Author proposed to obviate this by keeping down the crest of the training-walls to as low a level as might be consistent with the object to be effected, thereby avoiding interference with the influx of the flood-tide; but Sir Bradford Leslie feared this would not arrest the silting of the disused channels. As to the fascine-mattress training-walls deposited in the channel of the river, even if these were not destroyed by the *Teredo*, they would, he feared, be swallowed in the quicksand of the river-bed in a few tides, and if they chanced on a bit of hard ground the flood-tide would pick them up, carry them along, and strand them at some point where they might exercise an influence exactly contrary to that intended. When the S.S. "Egeria" wrecked the floating bridge at Calcutta during its construction, an iron plate girder of the superstructure, 100 feet long, with fragments of timber uprights attached, was carried by the bore 16 miles up river, and deposited on the Serampore sandbank. The scouring action of the ebb-tide was very great. A ship grounding on a sandbank, by deflecting the current downwards, dug her own grave, and tumbled into it on the flood-tide, and in a few days she was buried out of sight. In the same way scour along the fascine training-wall would cause it to tilt over, and it might either be swallowed up altogether, or be so thrown out of line as to become an obstruction to the channel. For these reasons the fascine training-walls were not only unlikely to effect the object intended, but might be productive of serious injury to the channels of the river. The improvement of the James and Mary reach, and the training of the ebb-tide into the flood-channel on the right bank of the river between Fulta and Gewankhali, in order to secure a permanent deep channel, were so important for the improvement of the navigation of the river as possibly to render it expedient to accept the risk of a certain amount of silting between tidal range on the left bank. The diversion of the ebb-tide into the flood-tide channel could be effected only by an oblique spur of heavy rubble stone extending from the left bank of the river at a point about 1 mile below Fulta Point. The spur would project to between the 3-fathom and the 4-fathom line. It should be fanned out at the end to a very flat semi-cone, so that the current impinging on the upper side would be deflected and glide off the end without exciting eddies. If the end of the spur were formed with an abrupt slope, such as stone naturally assumed when thrown in from the top, the diverted stream would swirl round the spur-end and expend its momentum in boring out a deep hole on the down-stream side; and the object of training the ebb-stream across into the flood-channel would not be attained. By means of stone spurs properly formed and located, the whole ebb-current could be deflected and caused to flow in any desired direction; and it would continue to flow in such direction until it met with further obstruction. If this were soft, it would soon be cut away; if it were hard, dredging might have to be resorted to, to allow the current to flow in the desired direction. A complementary stone spur might become necessary between Gewankhali and Luff Point, to check erosion caused by the concentrated ebb-tide which would impinge at Gewankhali. The necessity for such a spur could be ascertained only by actual experience. The material for the core of the spurs would be brick rubbish, a trade refuse which the brick-burners at Akra and elsewhere on the river-banks were glad to get rid of. The shield of rubble stone for protecting the upper side of the spur from scour would come from the neighbourhood of Sahibganj, Rajmahal, or other stations of the East Indian Railway, on the banks of the Bhagirathi River, where it could be put direct into boats and floated down-stream to the site of the spur. No skilled labour would be required. Sir Bradford Leslie.

Mr. Luigi.

Mr. Luigi Luiggi remarked that in dealing with the improvement of such large rivers as the Hooghly, the Mississippi, the Rio Paranà, and the Rio de la Plata, it was impossible to come to any really definite conclusion; for in magnitude they could not be compared with any rivers already improved, and usual experience could not be applied to them, except with the greatest caution. He agreed with the Author that the different reaches of each river must be treated separately, applying the most appropriate means for each case—such as submerged training-walls where the river wandered from bank to bank, with the help of dredging; always taking great care not to diminish appreciably the quantity of tidal

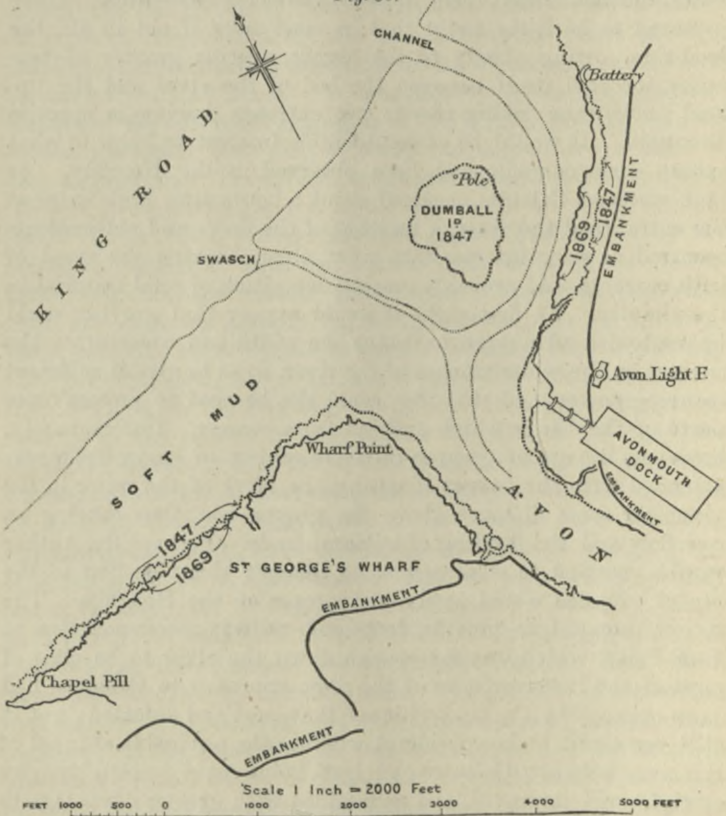
Mr. Luiggi. water that could flow in or out. In some sharp bends of the river a cut, as suggested for Fulta Point, might be useful. But all these works, besides being very costly for a very large river, were always somewhat uncertain in their final results; and therefore they should be undertaken only when all the chances of success had been properly weighed and found fairly promising. Dredging, on the other hand, when done with powerful machines and carried on actively, had always yielded satisfactory results from a technical point of view, and lately also from a financial point of view, thanks to the economical conditions under which such work could be carried out nowadays. It was not a permanent solution, because of the continual silting-up of the river; but its financial success was surer than that of costly training-walls—at least in very large rivers. The River Paranà and the entrance-channels to the port of Buenos Aires, cut across the mud of the south bank of the Rio de la Plata, had been treated almost exclusively by the remedy of dredging, with fair success from the point of view of both navigation and cost of maintenance. Young nations often could not afford the great initial outlay necessary for big training-walls, cuts, and other hydraulic works; whereas they could buy very powerful dredging-plants, and support the yearly expense of their working for the benefit of navigation. Although costly, this remedy in the case of young nations was almost the only one advisable, especially in view of such considerations as the rapid development of the natural resources of the country, which would lie dormant without these helps to navigation. For instance, Argentina could never have reached so rapidly such a high point of development of its agriculture without its ports, although they had to be kept open by continual dredging at a very large yearly outlay, and yet moderate in comparison with the great cost of construction, maintenance, and subsidiary dredging that would have been entailed by training-walls. The problem of improving very large rivers thus developed more into a financial problem than to a technical one, depending for its solution upon a choice between very heavy initial outlay of capital and a yearly outlay for maintenance; the first solution being preferable where capital could be had at low interest, and the second where the rate of interest was high. Good and ample buoyage—especially with luminous buoys—kept always up to date in respect of dredging and the changing position of the deepest part of the navigable channel, was a great help to success, as it confined the dredging into reasonable limited zones. This was especially important in the sea-reach of the river at its outlet.

Mr. I. J. MANN observed that the Author's full description of the tidal portion of the Hooghly, while furnishing almost sufficient information for devising a scheme for the much-required improvement of the river between Calcutta and the sea, indicated that many formidable difficulties would have to be overcome. In considering the regime of such a river as the Hooghly the action of the tidal water, regarded as separate from that of the upland water, did not always seem to receive sufficient attention. There appeared to be little doubt that in most cases, if not in all, the flood-tide, owing chiefly to the higher specific gravity of sea-water, inserted itself between the bed of the river and the upland water, thus giving rise to two currents flowing in opposite directions. It would be of considerable interest to know to what extent such currents had been observed in the Hooghly. As high water at Calcutta occurred about 5 hours after high water at the entrance of the river, a meeting of the flood- and ebb-currents occurred at some intermediate point, thus checking the speed of both currents, and probably causing deposition of solid material in the vicinity. At first sight it would appear that groynes could be used with advantage to reduce the width and concentrate the current in the wider reaches of the river, so as to give it sufficient scouring-power, and that they could also be used to protect those parts of the banks which suffered from erosion. Unfortunately, however, the use of groynes in rivers subject to heavy floods was attended with the danger of raising the level of the water in the river for some distance above the groyne and thus causing an overflow and the flooding of adjacent lands. Perhaps the Author would mention to what extent he thought this objection to the use of groynes would apply in the case of the Hooghly. The recent proposal to provide dock- and railway-accommodation at Luff Point, which was far enough down the river to be clear of most of the inconvenience of the river approach to Calcutta, had been opposed by the authorities of that port and defeated; but it still remained to be considered whether the navigable channel of the river between Calcutta and Luff Point could be satisfactorily straightened, improved, and maintained with greater advantage to shipping than the establishment of an out-port such as that proposed in the Luff-Point scheme. Mr. Mann.

Mr. A. WHARTON METCALFE considered that, while it was a far cry from the Hooghly to the Somersetshire Avon—not only geographically speaking but also as regarded size and length, area of country drained, etc.—there were nevertheless certain points of similarity between the two rivers. Both were silt-burdened to an extraordinary Mr. Metcalfe.

Mr. Metcalfe. extent; both were tidal rivers, and both ended in deltas, contrary, as the Author pointed out, to the prevailing type of tidal river: for Dumball Island was undoubtedly the delta of the Avon. He questioned, however, whether the delta was in this case due to accumulation, or was not rather due to the Dumball area being cut off from the mainland by the erosion of two channels of different

Fig. 30.

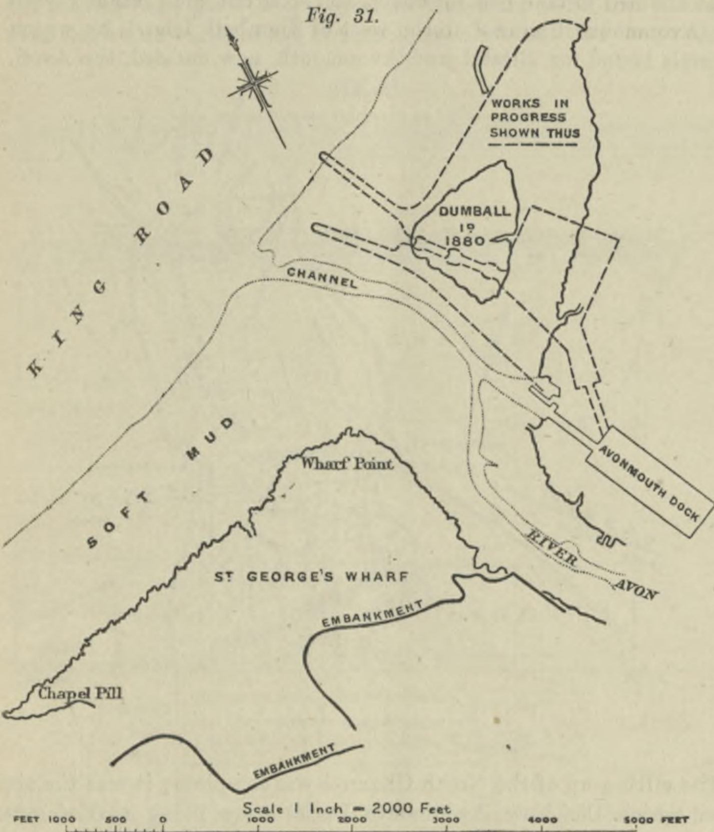


antiquity, each of which might in turn become the more important as circumstances changed. A large amount of erosion was taking place in the alluvial flats bordering the Severn and the mouth of the River Avon. Along the banks of the Severn both east and west of Avonmouth the erosion was rapid but normal, being due entirely to natural causes, such as the action of currents

Mr. Metcalfe.

or waves; whereas along the Avon, as far up as Pill, the ordinary causes of wastage were assisted by mechanical action, such as the wash created by passing steamboats which undercut the banks. He had found the shrinkage of the shore, due mainly to this cause, to amount to many feet in a few months. The trouble had been satisfactorily stopped, where very pressing, by the

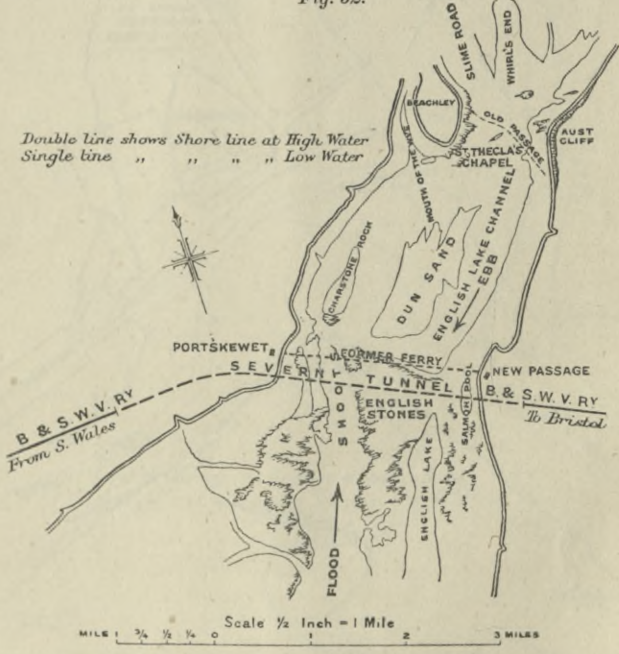
Fig. 31.



Severn Commissioners and the Bristol Docks Authorities, by protecting the foreshore with an apron of large loose stones, a remedy which would have to be considerably extended where the alluvium was cut back by the tide to the flood-banks. He would like to call attention to the case of extraordinarily rapid erosion in one place, and silting up in another, exhibited by *Figs. 30* and *31.* The channel east of Dumball Island, known locally

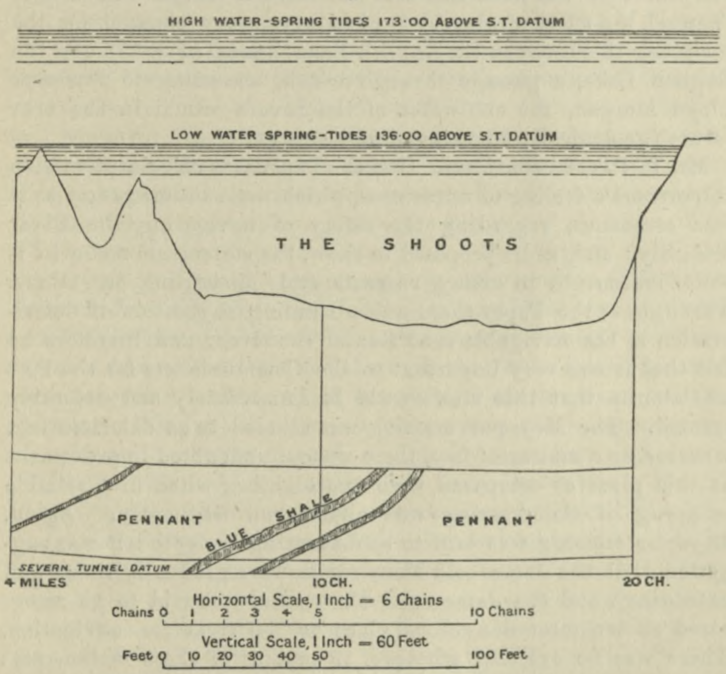
Mr. Metcalfe. as the North Channel, was the navigable channel prior to 1865 for vessels bound for Bristol; this channel began to silt up soon after the erection of the pier for the New Passage Ferry, which was believed to have diverted the portion of the current which kept the North Channel open; and at the same time, the outflowing water of the Avon, on account of the closing of the North Channel, was enabled to take greater effect, and so to cut the present Swash or Avonmouth Channel to the west of Dumball Island, by which vessels bound for Bristol and Avonmouth now entered the Avon.

Fig. 32.



The silting-up of the North Channel was complete; it was the site on which the New Avonmouth Docks were being carried out, and could in 1901 be crossed on foot when the tide was out; and land had accreted. On the other hand, by erosion the new channel, formerly only accessible to small craft, had become the main entrance-channel to the Avon for all classes of shipping. A remarkable instance of erosion of the bottom was illustrated by *Figs. 32* and *33*, the case of the Shoots Channel in the Severn on the site of the Severn Tunnel. A bed of half-tide rocks extended squarely almost the whole way across the Severn just below the site of the former ferry between New Passage and Portskewet (*Fig. 32*). These rocks were known as the English Stones; they terminated at the Shoots Channel, and in the opinion of the late Mr. Charles Richardson, M. Inst. C.E., it was to their abrupt termination and to the peculiar set of the tidal currents in the locality that the formation of the Shoots Channel was due. On the ebb-tide, the waters above half-tide level had a free passage over the whole width of the Severn; but below half-tide the ponded Mr. Metcalfe.

Fig. 33.



waters above the English Stones had to be discharged through the 400-yard wide gap of the Shoots Channel, and in the course of ages they had carved out that Channel (*Fig. 33*). The current, always very rapid, attained at times a velocity of 10 knots per hour, and was assisted in its work of erosion by vast quantities of coarse sand, gravel, and stones. When the foundations for the Portskewet Pier were being put in, the excavation for the footings of brickwork were filled with such materials after every tide, stones double the size of a man's fist being often found. With regard

Mr. Metcalfe. to the effect of the tidal currents in the formation of the Shoots Channel, it was found in ascending the river that the inflowing tide was directed towards the Welsh shore, while the out-flowing tide was thrown towards the English shore by the projecting point of St. Thecla's Chapel rock; in the slack water between the flood- and ebb-currents the Dun Sand had been formed, and this sandbank furnished much of the material with which the ebb-current was burdened. The Shoots Channel was washed to a depth of 52 feet below the lowest level of an ordinary spring-tide. The effect of the flood-tide was therefore to deepen the Shoots Channel, the effect of the ebb was to carve a new channel for the out-going tide between the English Lake channel (*Fig. 32*), and the English Lake, a passage through which, according to Professor Lloyd Morgan, the ebb-water of the Severn would in the near future (geologically speaking) find its way.

Mr. Palmer. Mr. F. PALMER considered that the Paper was calculated to give shipowners a feeling of uneasiness, which was as unnecessary as it was erroneous, regarding the safety of navigating the River Hooghly; and, as he proposed to show, the statements made in it were inaccurate in many respects and misleading in others. Throughout the Paper there was a running suggestion of deterioration in the navigable condition of the river; and therefore he felt that it was very important to the Commissioners for the Port of Calcutta that this idea should be immediately and definitely refuted. The Moyapur crossing was alluded to as deteriorating, whereas, as a matter of fact, there was an undoubted improvement at this place as compared with the eighties, when first reliable mapping of the crossing was undertaken frequently. Again, Royapur crossing was said to be decreasing in depth; it was suggested that the James and Mary sands were gradually rising and extending; and the James and Mary shoal was said to be recognized as the most dangerous place on the river for navigation. There was no evidence whatever in support of these statements: on the contrary, there had been a marked betterment of late years in the navigable condition of this well-known bar. In his conclusions regarding the improvement of the navigable condition of the Hooghly (p. 29) the Author stated that between Calcutta and Kulpi the improvement of the river was very important, and that there was a gradual reduction in the navigable depth at the Moyapur and Royapur crossings and, in parts, of the James and Mary reach; but the river-surveys from 1881 to the present time showed distinctly that, notwithstanding fluctuations from year to year, there was a general tendency to an increase in the navigable depth. A bar at

Mr. Palmer.

Ninan after seasons of high freshets was said in the Paper to have been regularly developed only within the last 20 years; but in the reports of the Committee appointed by the Government in 1853 to inquire into the state of the Hooghly, the "Ninan lumps" were described as being very troublesome from their sudden and unexpected changes; while the evidence of the witnesses examined, including sixteen pilots, was almost unanimous in its allusion to the difficulties experienced at the bar. In regard to the Author's assertion that all the surveys of the river were made in the dry season, and that the state of the river reached in that season was therefore the only one recorded in surveys, as a matter of fact, surveys of the river were being continually made in all conditions of tides and freshets. At least twice a month, throughout the year, surveys were made of all the channels from Calcutta to Saugor; and wherever there was the least tendency to a change in these channels, daily surveys were made. Nearly one thousand charts of various parts of the river were now published annually, and the Commissioners possessed very accurate records of the state of the whole river at every season of the year. The Author stated that there were no signs of any approaching deterioration of the main channels from the sea to the Hooghly estuary, that was, to Kulpi; but, to show how opinions varied on this question, it might be pointed out that two of the three members of the 1853 Committee came to the conclusion that, while the portion of the river between Calcutta and Kulpi had shown no deterioration, the "preponderance of evidence" clearly showed a deterioration below Kedgeree (Khijiri). The third member of that Committee (Mr. H. Piddington), on the other hand, was most emphatic in his opinion that, generally speaking, no deterioration had taken place. In his separate report Mr. Piddington said [1]:—

"Reviewing then the whole of the evidence, parole and documentary, which we have obtained, and giving to every part of it my best consideration, I am of opinion that up to the close of the year 1853, there is no fair ground for supposing that the Hooghly has *upon the whole* deteriorated, from Calcutta to the sea, as a navigable river, during the present century. . . I fully concur in the view . . . taken by so many of the best informed of the witnesses that 'as one channel shuts up another opens out'; so that I find nothing to lead us to anticipate any future deterioration beyond such as may arise from a temporary shallowing of some of the difficult channels while a change is going on near it."

Fifty years' further experience of the Hooghly had only shown the extreme accuracy of Mr. Piddington's conclusions; and no better proof could be given that the river had, to say the

[1] "Reports . . . of the Committee appointed . . . to inquire into the state of the River Hooghly," p. xix. Calcutta, 1854.

Mr. Palmer.

Year.	Number of Vessels of 21 Feet Draught and over navigating the River Hooghly. Draught. 21–22 Feet.	22–23 Feet.	23–24 Feet.	24–25 Feet.	25–26 Feet.	26–27 Feet.	27–28 Feet.	Over 28 Feet.	Casualties. Total Losses in Periods of 10 Years. Years.	No.	Maximum Casualties of all Classes in the worst Year of the 10-Year Periods, expressed as a Percentage on the Total Number of Vessels.
											Per Cent.
1860	57	10	..	..	..	..	..	..			
1870	163	55	4	..	..	..	..	..	1865–74	15	5·6
1880	245	185	75	29	4	..	..	..	1875–84	7	3·7
1890	235	227	179	94	12	1	..	..	1885–94	3	3·0
1900	148	204	287	235	130	22	1	..	1895–1904	2	1·3
1903	125	155	259	250	167	71	15	1	1903–1904	Nil	0·9

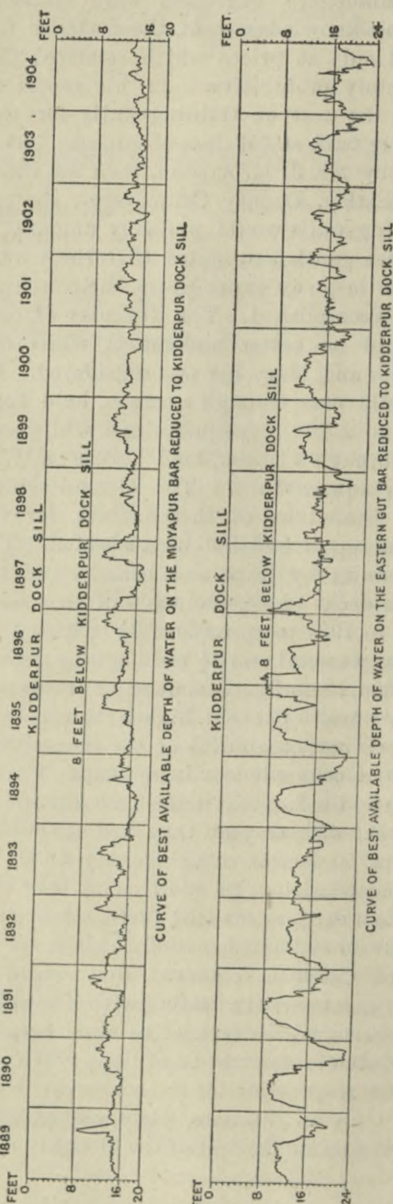
least, shown no sign of deterioration, than the above statement compiled from the records of vessels trading to Calcutta. The number of vessels of 21 feet draught and over navigating the river during the past half century was shown for the years named; and the total losses, as well as *all* casualties (most of which were very trifling groundings) showed conclusively that, while the size and draught of vessels was increasing year by year the percentage of accidents was rapidly diminishing. In the early history of the city and port of Calcutta it was recorded that a vessel of 500 tons burden had to discharge one-half of its cargo into lighters at the mouth of the river, as it was considered unsafe for so large a vessel fully laden to attempt the passage up to Calcutta. Now, steamers like the "City of York" made regular trips to and from Calcutta, carrying about 12,000 tons of goods and more than 150 passengers. With regard to the fresh-water discharge of the Hooghly past Calcutta, which the Author estimated at a maximum of 650,000 cubic feet per second, observations taken during August, 1904, when the freshets were more than ordinarily strong, indicated a maximum discharge during 24 hours of about 300,000 cubic feet per second; while the average for the whole month was about 250,000 cubic feet per second. A discharge of 650,000 cubic feet per second would give a velocity of about 13 feet per second over the whole cross section of the river; and there was nothing to show that such a high velocity had ever been observed in the entire width of the stream. As to the material available for the construction of training-walls of fascine-mattresses, the Author might have information on this head which the Commissioners' engineers were entirely ignorant of; but so far as their knowledge went, the material for such work could be obtained only at prices which rendered the adoption of this plan absolutely prohibitive. In his report of 1896 the Author estimated the cost of training-walls for the James and Mary and Moyapur bars at 25$\frac{3}{5}$ lacs of rupees; but a Note[1] on his report written by Mr. J. H. Apjohn, then the Chief Engineer, and Mr. E. W. Petley, Deputy Conservator, showed that the cost of these training-walls would probably amount to 174 lacs of rupees; and these gentlemen stated that they were not confident that, even for so large an expenditure, the construction of the works could be accomplished. The difficulty of constructing training-walls could be better understood when the material composing the James and Mary bar was considered. Of this sand 55·5 per cent. would pass through a screen, held horizontally, of 10,000 meshes (100 × 100) per square inch, while only 1 per cent. would not pass through a screen, held horizontally, of 4,900 meshes (70 × 70) per square inch. The Commissioners appeared to have accepted the advice of their officers, for the recommendations made in the report had not been adopted. The trade of the port was increasing by leaps and bounds, and the export trade handled at the docks alone, exclusive of that dealt with in the river, amounted in 1904 to upwards of 3$\frac{1}{4}$ million tons, of which about 2 million tons was coal and 1$\frac{1}{4}$ million tons general cargo. As compared with 1903, these figures showed an increase of about 25 per cent.; and they were 50 per cent. higher than in 1902. That the Commissioners were not unmindful of the necessity of improving their facilities and conveniences in advance of trade requirements was best shown by the fact that in the 9 months ending with December of the current official year they had sanctioned the expenditure of more than 50 lacs of rupees (nearly £350,000) for providing further accommodation. In addition to this they purposed purchasing at once a dredger for still further deepening the channels over the bars at an estimated cost of £60,000. Mr. Palmer.

Mr. Eaton W. Petley, of Calcutta, observed that while the Author had evidently taken great pains in dealing with his subject, the mere study of annual charts, which seemed to have been his method of arriving at his deductions, could be of little real value, either to himself or to those responsible for the conservancy of a river of this description. Only an intimate, daily, and extended experience of what was going on in the bed of the Hooghly could Mr. Petley.

[1] A copy of this Note is in the Library of the Institution.—Sec. Inst. C.E.

Mr. Petley.

Fig. 34.



possibly give an engineer a practical idea of the difficulties he would have to contend with in attempting to control the waters of this river. In order to substantiate these views Mr. Petley would point to the following statement (p. 30):—"In the first place, the gradual widening of the river at the Moyapur and Royapur crossings, and in parts of the James and Mary reach, is leading to a gradual reduction in the navigable depth over the crossings, and a progressive deterioration in the navigable condition of the James and Mary reach by a growth of the central shoal." It might surprise the Author to learn that there was no progressive deterioration in the James and Mary, the Royapur, or the Moyapur crossing. This was demonstrated by *Fig. 34*, which showed the obtainable navigable water for the last 16 years. It indicated that the two principal bars had unquestionably improved, which was exactly the reverse of the statement made by the Author. There was therefore no justification for the statement that this deterioration was inevitable. For

Mr. Petley.

the last 8 years the James and Mary bar had never shoaled below 10 feet 3 inches, and in 1904 the minimum depth had been 13 feet. The greatest deterioration of recent years had occurred in the latter part of January 1897, when the bar had only afforded 6 feet 3 inches for 2 days; but this had been the direct result of the wreck of the S.S. "City of Canterbury" on the James and Mary shoal, and not a natural shoaling; for although the water on the bar previously fell to 9 feet 6 inches, it had begun to deepen again when the accident occurred. During the last 10 years the Moyapur bar had not shoaled below 10 feet; and this contrasted very favourably with the best water obtainable in 1886, which was only 7 feet 9 inches. With regard to the Royapur bar, Mr. Bedford, the River Surveyor, stated in 1854 that 7 feet 9 inches was the average available depth in May; and this level had been touched only once in recent years, for a few days. The least depth of this bar during 1904 had been 14 feet 6 inches on one day, otherwise it had afforded a fair channel; and on the whole Mr. Petley considered that if the regime of the Hooghly with regard to its principal bars was not steady, the balance was in favour of improvement. In face of the fact that in 1903 a ship navigated the Hooghly safely with a draught of 28 feet 3 inches, the anxiety and alarm to which irresponsible people gave expression about the river was unfounded. With regard to the central shoal referred to on the James and Mary reach, it was only a coincidence that the shoal was showing a progressive deterioration: at times this shoal nearly disappeared below low-water level. Having regard to the mis-statement of fact which he found in one paragraph alone, he could not look upon the remainder of the Paper seriously. But he desired to state that the Commissioners of the Port of Calcutta were fully alive to the importance of conserving their channels; and their officers were preparing their own schemes for keeping the water-way between Calcutta and the sea open to ships of deep draught at all seasons of the year. In the circumstances explained above, the Paper could not assist in arriving at any practical results on such an abstruse problem. On the other hand, the incorrectness of some of its statements must tend to disturb the minds of those commercially interested in the welfare of the port, and must incline them to think that the Conservators of the river were taking no steps to improve the water-way. Mr. G. Robertson had expressed[1] the opinion that the Hooghly was

[1] G. Robertson, "Reports to the Government of India on Indian Harbours," 2nd series, p. 15. *Edinburgh*, 1873.

Mr. Petley. not a river for experimenting; to which Mr. Petley would add that its vagaries must be dealt with only by those who had a practical and daily knowledge of its ways.

Mr. Reinhold. Mr. ALFRED REINHOLD, Chief Engineer of the Danube Regulation-Works, considered that the chief obstacles to the improvement of the River Hooghly, and to the provision of a safer navigable channel between Calcutta and the sea, were the sharp bends in its course and the heavy floods of the tributaries during the rainy season, in conjunction with the tides. The tidal influence must not be hindered by sharp bends, such as at Hooghly Point, which was the most difficult situation, on account of the discharges of the Rupnarayan, especially during heavy floods. Realizing this inconvenience, Mr. Brooks had proposed a cut through Hooghly Point—a costly work, which doubtless would have effected an improvement for navigation. Cuts should be made between Buj-Buj and Royapur and at Hangman's Point, in connection with regulation by training-works in other parts of the river. The tidal influence should be powerful; and in consequence there should be a deepening of the shoals, but to what extent it was impossible to predict. The cost of these works would certainly be very heavy, as the three cuts might require nearly 105 million cubic yards of excavation. Training-works alone, without the three cuts, might be successful; but the action on the shoals would be but slight. Training-works on the banks were costly, and some time must elapse before their influence on the currents of the river, and on the crossings, became manifest. The regulation of the Danube for mean water near Vienna on a length of 140 kilometres (88 miles), with an embankment of 59 kilometres (37 miles), during 34 years, had cost down to the present day 74 million florins (£7,400,000). A canal with locks, of the same length, would not have cost more. None of the various schemes for cuts and training-works would provide the depth of water in the Hooghly necessary for ocean-going ships with a draught of 26½ feet to reach Calcutta at any time; and it was essential that such ships should be able to reach the capital of India. The improvement of the Hooghly for navigation might be dealt with by the following methods:—(1) The regulation of the estuary from Kantabaria to the sea by fascine-works to give a depth of 26½–29½ feet; these would partially improve the course of the river by augmenting the influence of the tide, especially in the length between Kantabaria and Hooghly Point. (2) The construction of a ship-canal from Hospital Point to Calcutta, a length of 34 miles, with a depth of 26 feet and a bottom width of 120 feet: this would render the passage of large ships to Calcutta

Mr. Reinhold.

convenient and safe at any time. The ship-canal would be cut through Hooghly Point, and closed at Hospital Point by a lock; a length of 9 miles being carried along the left bank of the river between Hooghly Point and Brul. The excavation in a length of 25 miles between Brul and Calcutta, and through Hooghly Point, might be about 30 million cubic metres.

Mr. Robertson.

Mr. F. E. ROBERTSON was in entire agreement with the conclusions of the Paper, especially in regard to the preference for a continuous work to isolated spurs, and the condemnation of Mr. Lindon Bates's proposals for works on the convex banks of bends. The subject of the exact form of training-works for improving the crossings between the bends in rivers had been very elaborately treated by Mr. Fargue;[1] and though problems of this kind could not be disposed of by pure mathematics, yet Mr. Fargue's Paper was well worth study. As to the cuts which might improve the navigation, what the engineer had to consider was the commercial, and not the physical possibility of a work; and the cost of these works put them out of the question, even were the result more certain than it appeared to be.

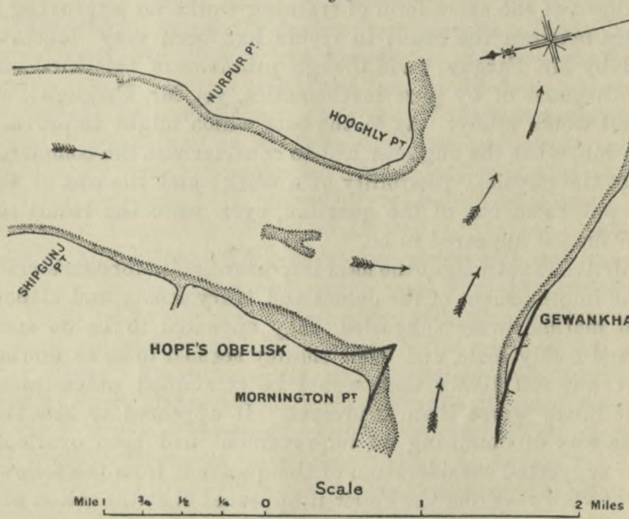
Mr. Saner.

Mr. J. A. SANER thought the most important point for consideration was the improvement of the James and Mary shoal; and although several methods were suggested, they appeared to be on such a large and costly scale, and their efficacy seemed to be so doubtful, that it was not likely they would be attempted unless matters became much worse than at present. It appeared to him that a feasible way of obtaining an improvement had been overlooked, and he suggested consideration of the question from the following point of view:—From the Paper it appeared that the action of the Rupnarayan river was a considerable agency in the formation of the shoal. The rapid freshets of this river, which came in more or less at right-angles to the direction of flow of the main river, must cause considerable eddies in the immediate neighbourhood, more especially on the up-stream side, checking the downward flow of the main river during the time a freshet or the ebb-tide was flowing down, with, of course, a longer period than that of the inflowing tide. It was not stated whether any large portion of the tide flowed up the Rupnarayan; but in any case during the whole period of ebb there must be a discharge from this river maintaining in a greater or less degree the checking and diverting action. A portion of the flood-tide also had to flow up the Rupnarayan, and, striking Mornington Point, it caused eddies in the same place as

[1] *Annales des Ponts et Chaussées*, 7th series, vol. vii. (1894), p. 426.

Mr. Saner. the river caused them during freshets and ebb-tides. If the waters of the Rupnarayan were directed more in a seaward direction by a groyne or training-wall, forming an extension of Mornington Point, and if a small amount of land were removed from the point of Gewankhali, somewhat as indicated in *Fig. 35*, a confluence of the two streams would be gradually accomplished, the checking action on the downward flow would be done away with, and the channel would be brought more into the centre of the river, while the in-flowing tide would not be materially interfered with. Such

Fig. 35.



a groyne or training-wall would be of small cost compared with the works proposed in the Paper, and if constructed of piling and planks as an experiment, it could be removed should it be found to be of no use, or in any way detrimental. In putting forward these proposals he had relied entirely on the information given in the Paper, having no previous knowledge of this particular sandbank.

Mr. Schild. Mr. A. Schild, of Vienna, remarked that 26 years' experience of the regulation of different rivers convinced him that the proposed method of improving the defective reaches of the River Hooghly by the concentration of the flood- and ebb-tide currents into a single channel, that was to say, by diverting the ebb-tide or descending current and directing it gradually across the river into the flood-tide channel along the other bank, was really the best method of increasing the available depth of the navigable channel, and the only true solution of the difficulties. He could not agree with the proposals made by Mr. Lindon Bates. The works proposed by that gentleman did not seem at all capable of effecting the desired improvements; and in particular the reclamation-works over the sandbanks projecting from the convex banks would help to sharpen the bends still more, and affect prejudicially the navigation of the river. Mr. Schild.

Professor G. H. DE THIERRY, of Berlin, stated that at the end of 1899 Mr. Lindon Bates asked his advice on the project he had submitted earlier in the same year to the Harbour Commissioners of Calcutta. The results of the Author's profound study of the River Hooghly, as set forth in his interesting report published at Calcutta in 1897, had been the basis on which Mr. Bates had founded his project; and Professor Thierry had studied this report before giving his opinion on Mr. Bates's project. He thought every engineer who took an interest in the improvement of tidal rivers must feel thankful to the Author for his interesting account of a river which presented such peculiar features. At the same time, he fully agreed with the conclusion that there was no feature in the condition of the Hooghly which rendered it incapable of improvement. As the Author remarked, the tidal influx had to provide the navigable depth over the shoals at high tide for two-thirds of the year, and therefore the first thing to be done was to improve the tidal propagation into the river. The shoals and sharp bends undoubtedly checked the progress of the tide; but he did not think the appearance of the bore, and the fall of the high-water level above Kidderpur, both of which were evidence of abnormal tidal propagation, could be attributed solely to these obstacles. If this were really the case, the low-water line would be far more irregular than it seemed to be according to Figs. 4 and 6, Plate 2. He was inclined to make the Rupnarayan responsible for these phenomena, and he thought the characteristic profiles (Figs. 4 and 6) demonstrated unquestionably the influence of the Rupnarayan basin. During the first 2 hours and 40 minutes of the flood (from 6 A.M. till 8.40 A.M.) nearly the whole of the incoming tide flowed into the Rupnarayan. After this time, the sands in the estuary being probably covered, the volume of water passing Hooghly Point seemed to be sufficient not only to finish filling the basin of the Rupnarayan, but also to fill the basin of the Hooghly. At this time, however, the level of the tide in the Hooghly, above the outlets of the Damuda and Rupnarayan, was still so low that the flood rushed into this vacuum, creating the bore. The disappearance of the bore during the rainy season, was, he thought, due to the Professor de Thierry.

Professor de Thierry. fact that, owing to the vast volume of fresh water coming down the Hooghly, as well as the Damuda and the Rupnarayan, there existed no vacuum which must be filled by the flood-tide. Therefore, before executing regulation-works on the Hooghly itself, the principal cause of all the troubles ought to be dealt with: that was to say, the first operation must be to reduce sensibly the indraught of the Rupnarayan. These works alone, however, could not improve sufficiently the actual situation. The Ninan bar, and the difficulty of navigation past Fulta Point, were independent of the action of the Rupnarayan, and were caused by the actual defective alignment. After improving the tidal propagation of the Hooghly by reducing the indraught of the Rupnarayan, the present high velocities of the flood-tide on the Hooghly would be greatly reduced; but the velocities along the concave banks during the rainy season, when the fresh-water discharge attained its maximum, would always be so great as to render the construction—and, supposing this to be successful, the existence—of a training-wall like that proposed by the Author a most hazardous enterprise. The rectification of the double concave at Fulta Point, as proposed by Mr. Bates in connection with training-banks at the Damuda outlet to normalize the widths, was a solution which presented the certainty of success. It had, besides, the great advantage that its execution need not interfere with the interests of navigation. With respect to the improvement of the Royapur and Moyapur bars, he considered that this improvement could be obtained only by reducing the present abnormal low-water widths: but he did not think the Author's proposals were fully satisfactory. The tops of the training-walls ought certainly to be kept low; but the walls ought not to be built like spurs, and they should be connected, especially in a tidal river, to the bank, not only at their upper, but also at their lower ends; and better results would be obtained by raising the tops of the training-walls to the level of low water, keeping the walls at the same time nearer to the bank.

Mr. Wyness. Mr. James Wyness, of Calcutta, remarked that no notice seemed to have been taken in the Paper of the fact, well known in Bengal, that the channel of the Bhagirathi was deteriorating. The evidence of this was not based on cross sections of the river, as these had seldom been taken, and no care has been exercised to take remeasurements of the same section, so that successive measurements might or might not be measurements of a cross section at the same place. It was a matter of common knowledge, however, that the available depth of water over the bars in the Bhagirathi in the dry season had been less in recent years than formerly, and at the same time

Mr. Wyness.

the dry-season level of the water, as shown by the gauges, had been higher than before. As the shoals, over which a greater height of water had afforded a less depth, aggregated about one-fifth of the total length of the river, it was clear that the bed of the Bhagirathi was rising (by about 2 inches per annum), and that the channel tended to close. Owing to the greater mileage, greater curvature, and less mean slope of the Bhagirathi channel compared with the Ganges, the current of the Bhagirathi flowed with less velocity than the current of the Ganges; and this reduction of velocity on entering the Bhagirathi caused a tendency to silt up and raise the bed of the river, which must continue until the bed was so far raised that only in exceptional floods would any water pass from the Ganges into the Bhagirathi. This action, once definitely established, was likely to grow more rapid, because of the progressive increase in the length of the channel by erosion of the concave banks in the bends. The "dying" tendency of the Bhagirathi river was generally attributed to other streams of the western portion of the Ganges delta, although, as in the case of the Bhagirathi and upper reaches of the Hooghly, no reliable surveys were available. It might be mentioned, however, that as a result of the Author's report of 1896 and the representations of the inland steamer-companies, who were of course deeply interested in the conservation of the waterway to the main Ganges stream, a survey of the Hooghly between Calcutta and Nadia had at last been commenced; and the delay in carrying out this operation pointed to the inadequacy of the staff at the disposal of the River Survey. On this question of the decline of the rivers of the western delta some interesting remarks had been made by Mr. La Touche, of the Geological Survey of India, before the Asiatic Society of Bengal, in connection with a discovery of fossil oyster-shells in excavating for the foundations of some new buildings in Clive Street, Calcutta. Mr. La Touche considered that the discovery of these sub-recent deposits near the present surface, coupled with the ascertained fact that evidence existed of sunken beaches at depths several hundred feet below mean sea-level, would point to subsidences alternating with more or less general upward movements; and the tendency to close which appeared to be the main feature of the history of the western delta in the last few hundred years might be so explainable. The Author had done service to the elucidation of the Hooghly problems by pointing out the necessity of the fresh-water discharge of the Hooghly for the maintenance of a deep channel, and he showed by implication that the Mutla as a navigable river was doomed.

Mr. Wyness. Schemes which had been suggested from time to time for making use of Port Canning as a sea-port had been put forward in ignorance of the elementary facts upon which stress was rightly laid by the Author. The Author referred to the changes which had taken place in the Damuda, and to the fact that the deterioration of the James and Mary reach was partly due to the diversion of part of the water of the Damuda into the Rupnarayan; but he did not mention that the alterations which had taken place in the Damuda channel about 60 miles above its mouth indicated the probability of further diminution of the water now discharged by the Damuda, if not its entire diversion to the Rupnarayan. The position of the Damuda discharge just opposite Fulta Point complicated the problem of the improvement of the James and Mary reach, and increased the difficulty of throwing the ebb-current into the flood-channel, the Western Gut, which, as the Author stated, was the only way in which a stable deep channel could be obtained in this reach. With the Damuda discharging as at present, the training-wall must be exposed to the Damuda current striking it at an undesirable angle, entailing greater expense and possible failure in putting in the wall; but if the Damuda discharge were lessened, the combined water of the Hooghly and the Damuda would tend to flow more or less centrally down the upper part of the James and Mary reach, and could without violence be directed into the Western Gut below Shipgunj. It was true, as pointed out in the Paper, that the diversion of the whole of the Damuda discharge from the James and Mary reach would render it difficult to train the channel satisfactorily, as the whole current of the Hooghly would be directed against the right bank below Fulta Point, and would be thrown off again by Shipgunj Point and directed towards Nurpur, making it impossible to unite the ebb- and flood-channels; and it was therefore to be hoped that the upper parts of the Damuda would be carefully watched, so that measures could be taken when necessary to prevent the Damuda discharge from being entirely diverted into the Rupnarayan. The improvement of the Moyapur and Royapur reaches presented a much simpler problem; and the easiest method of dealing with it was undoubtedly that proposed by the Author, namely to train the ebb-channel into the flood-channel. This had the disadvantage of increasing the curvature of the river, of promoting erosion of the concave bank, and, consequently, of lengthening the channel. The channel of the Bhagirathi and Hooghly already suffered by reason of its length, and it was of great importance that every effort should be made to prevent further lengthening. If, therefore, it was practicable to improve the Moyapur and Royapur reaches in any way that would not increase the curvature and would not conduce to lengthening the channel, it would be desirable to adopt such a scheme in preference to another. Instead of training the ebb-channel into the flood-channel, it might be almost equally easy to train the flood-channel into the ebb-channel by putting in a curved brushwood wall from the head of the deep pool opposite Hiragunj Point to about a point in front of the Moyapur Magazine. Similarly the Royapur bar could be dealt with by putting in a training-wall opposite Brul Point, to direct the flood-current over towards Royapur instead of allowing it to run into the tail of the Royapur Sand. Mr. Wyness.

The AUTHOR, in reply, expressed the pleasure he experienced from the international character of the Correspondence. Mr. Ellis attributed the winding course of rivers flowing through flat alluvial plains to the influence of tributaries; but though large tributaries introduced complications in the channel of the main river, as exemplified by the Damuda and Rupnarayan, there were many windings in such rivers as the Thames, the Seine, and the Mississippi where no tributaries entered; and even in certain parts of the Hooghly, Mr. Ellis had to assume the existence of tributaries which did not appear on the charts. The important regulation-works on the Danube in Austria, referred to by Mr. Bozdech, consisted of dipping cross dikes or groynes, and training-walls in front of the concave banks, and were designed to close secondary channels, and to concentrate the flow of the river at its lowest stage in a single, narrowed channel, suitably directed for the traffic, so as to provide a minimum depth of 8·2 feet: they resembled the regulation-works of the Rhone below Lyons and of the Upper Mississippi for inland navigation, and differed from the works applicable to the improvement of a tidal river for sea-going vessels. Mr. Mann, indeed, suggested the adoption of groynes for reducing the width and concentrating the current in the wider reaches of the Hooghly, and for protecting the banks from erosion; and Sir Bradford Leslie proposed to divert the ebb-tide current into the flood-tide channel in the James and Mary reach, by extending oblique stone spurs, or groynes, out from the left bank into a depth of 3½ fathoms, about a mile below Fulta Point: but, unfortunately, groynes had to be raised to a high level at their junction with the bank; they necessarily offered more opposition to the currents than a longitudinal training-wall; and unless they were connected together at their ends by a continuous training-wall, deep holes would be formed by eddies at their outer extremities, The Author.

The Author. producing considerable irregularities in depth in the scoured channel. With regard to Sir Bradford Leslie's fear that fascine-mattresses would soon sink into the quicksands of the river-bed, or if deposited on hard ground would be carried away by the flood-tide, such mattresses were far less likely to sink into the soft river-bed than rubble stone, especially when placed in the line of the current, instead of at right angles to the flow. Experience showed that fascine-mattresses, when properly laid on the alluvial bed of a river with a very large discharge, and duly weighted, were not in danger of being borne away by the current; for such mattresses had been securely deposited across the bottom of the bed of the deltaic passes of the Mississippi at their inlets, for regulating the proportions of the discharge passing down them. Dr. Corthell's advocacy of dredging was based on the successful formation of a navigable channel every year through bars of sand obstructing the bed of a part of the Upper Mississippi at its low stage, by several powerful sand-pump dredgers provided with water-jets for stirring up the sand; [1] but the dredging on the Mississippi was carried out in a river where the current always flowed downwards, and at a period when the discharge was at a minimum, and therefore under conditions quite different from those of the Hooghly, where the direction of the current was reversed twice a day owing to the tide, the flood- and ebb-tides followed different channels in some of the crossings between the bends, and the strengths of the flood-tide and the descending current varied according to the seasons. Mr. Luiggi proposed dredging from his knowledge of the results accomplished by this means in improving channels in the wide Paranà River and the estuary of the La Plata, which corresponded somewhat with the suction dredging the Author had proposed in his Report and in the Paper for directing and deepening to a moderate extent the navigable channel in the Hooghly estuary. Mr. Bellasis considered that training-walls below the lowest low-water would not produce sufficient scour, and that their down-stream ends would be liable to be caught by the flood-tide. In view, however, of the deep ebb-tide channel found alongside the concave bank near the crossings, the good height of the proposed training-walls above the river-bed, and the moderate increase in depth required in readily erodible materials, the scour created by the training-works seemed likely to prove ample: whilst accretion at the back would serve to protect the training-wall, whose down-stream end was well out of the

[1] See L. F. Vernon-Harcourt, "Report on the River Húgli," p. 95. Calcutta, 1897; and "Civil Engineering," pp. 48 and 49.

main run of the flood-tide; though, if found desirable, this end might readily be connected with the adjacent bank as suggested. Mr. Larminie, on the other hand, was of opinion that the training-walls shown in *Figs. 20* and *21* would cause erosion of the concave banks opposite; but it must be borne in mind that the proposed training-walls would not affect the channel in any way above the lowest low-water, and in the case of the Moyapur and Royapur reaches, for some depth below; that in these two reaches the flow of the freshets would be only slightly directed rather higher up to the opposite concave bank, and by the channel over the crossing thus produced would relieve this part of the bank to some extent from the scour of the flood-tide; and that the low-water channel, even outside the training-walls, would be decidedly wider than round Hiragunj and Brul Points. In the James and Mary reach the main flow of the freshets would follow the line of the training-wall, and would not be directed against Mornington Point. Moreover, any erosion at these places could be readily arrested by simple protective works along the concave banks. With the object of avoiding this anticipated erosion of the concave banks, Mr. Wyness suggested training the flood-tide into the ebb-tide channel, starting opposite Hiragunj and Brul Points, and going up-stream; but, in addition to the objections to this course stated in the Paper, such works would lie in the direct path of the freshets, would restrict the low-water channel at an already narrow part, and would be liable to cause increased erosion during the freshets in the concave bank just below the commencement of the training-wall. Moreover, the descending current, being continuous throughout the year, was better adapted than the flood-tide current, which was practically obliterated by the freshets in the upper reaches, for forming a permanently deep channel across the Moyapur and Royapur crossings. Mr. F. E. Robertson and Mr. Schild, while agreeing entirely with the improvement works proposed in the Paper, disapproved of the works proposed by Mr. Bates at Hiragunj and Brul Points, as shown in *Fig. 22*, which view was shared unanimously by the other engineers who referred to this scheme. Even Professor de Thierry, who, having been consulted on the matter in 1899, appeared as the advocate of the scheme for improving the James and Mary reach shown in *Fig. 23*, confined himself, in respect of the Moyapur and Royapur reaches, to suggesting modifications in the Author's proposals. The peculiar and defective conditions of the James and Mary reach had given rise to various schemes of improvement; and two engineers The Author.

The Author. had put forward proposals, for the thorough amelioration of the navigation from Calcutta to the sea, which made the Author astonished at his own moderation. In presenting schemes for the improvement of the Hooghly, the following considerations must be kept in view. In the first place, the improvements which might be relied on to be effected by certain works should be commensurate with their cost, which must be kept within reasonable limits; secondly, the existing banks of the river should be interfered with as little as possible, for fear that the cutting away of points, which were necessarily composed of hard materials, should lay bare softer strata, liable to be unduly eroded unless efficient protection was provided; and, lastly, in any works for the amelioration of the James and Mary reach, the conflict in the direction of the flood- and ebb-tide currents, which ran at right angles to one another in front of Hooghly Point, must be eliminated, and the two must be directed as nearly as practicable into a single channel. The training-work proposed by Mr. Saner at Mornington Point (*Fig. 35*) could have no influence on the main ebb-tide current running close along the left bank nearly down to Hooghly Point; and the same objection might be raised to a minor extent with regard to the larger similar work proposed by Mr. Larminie in *Fig. 28*, from which it appeared that Mr. Larminie was under the erroneous impression that the main descending current hugged the right bank below Shipgunj Point. As pointed out in the Paper, the removal of Fulta Point, proposed in *Fig. 25* by Mr. Crahay de Franchimont, as well as in *Fig. 23*, and also indicated in *Fig. 27*, though improving the general course of the river at a part where the present configuration was peculiar, could not of itself remedy the defective condition of the reach at its lower end. Professor de Thierry was under a complete misapprehension in supposing that nearly the whole of the flood-tide flowed into the Rupnarayan during the first 2 hours and 40 minutes of flood, or between 6 A.M. and 8.40 A.M. in Fig. 4, Plate 2, for the flood-tide occupied this period in flowing up the estuary and into the river as far as Hooghly Point; and, as clearly shown by Fig. 4, the tide there represented could not possibly flow at all into the Rupnarayan till after 8.40 A.M., when the flood-tide first reached Hooghly Point. In reality the flood-tide passed more freely up the Hooghly, owing to its greater width and better depth, than up the Rupnarayan, in which there was a minimum depth of only 3 feet in the channel a short distance above its mouth when the Author went up it with the early flood of a spring-tide. Mr. Crahay de Franchimont's scheme for the James and Mary reach (*Fig. 25*), was an improvement in several respects on that shown in *Fig. 23* in the Paper; for the cutting at Fulta Point was reduced, the ebb-tide channel was somewhat pushed away from the left bank, reducing the width of the reach and bringing the channel a little nearer to the flood-tide channel along the right bank. Hooghly Point was cut back instead of being protruded, the Damuda was given a more favourably directed outlet, and the projection at Mornington Point, in combination with the training-wall in front of the opposite bank, served to regulate the width of the channel. Those works alone, however, would not eliminate the conflict of the tidal currents, and the divergence of the channels at the lower end of the reach; but he gathered that in addition to this regulation of the high-water channel, Mr. Crahay de Franchimont proposed to form also a low-water channel, which, provided it received the main flow of the ebb and flood, would complete the improvement, though at a large cost. Mr. Keele, after expressing his approval of the works proposed in the Paper, indicated in *Fig. 27* an interesting combination of a cutting-back of Fulta Point with a training-wall beyond, terminating in a similar position to that shown in *Fig. 21* in the Paper; and, but for the cost, this might be regarded as a satisfactory remedy for the defective condition of this part of the river. Mr. Crugnola seemed disposed to favour the idea of diverting the discharge of the Damuda completely into the Rupnarayan, so as to do away with the complications it introduced into the flow of the Hooghly at Fulta Point; considering that if the ebb-tide channel was thereby directed over to the right bank above Shipgunj Point, it might be kept there by cutting back this point, which appeared feasible at the cost of a large alteration of the line of the bank: but if a cutting-off of any point there was to be undertaken, it appeared preferable to remove Fulta Point, so as to improve the general course of the river at that part. Mr. Crahay de Franchimont seemed to advocate the general training of the river below Calcutta, regulating a low-water channel by means of low brushwood spurs, and extending the training-works down to Diamond Harbour, which, though theoretically correct, appeared to be quite beyond the requirements of navigation and the funds which might be available for improvements. Mr. de Coene's formidable project, besides being evidently begun at the wrong end, completely disregarded the inevitable accretion which would take place in the estuary outside the trained channel, resulting in a great loss of tidal capacity, which would be followed by an extension The Author.

The Author. of the sandbanks seaward, especially on the eastern side. As to the scheme suggested by Mr. Reinhold, the regulation of the channel through the estuary was open to the objection mentioned above; whilst the cost of such extensive works, with the uncertainties attending the exposed estuary works, appeared absolutely to prohibit their execution. The difficulty of improving large winding tidal rivers, with obstructive shoals in places, did not consist in formulating comprehensive schemes for transforming the state of the river without regard to the cost, but in designing works which, while providing the essential increase in depth for navigation, could be carried out at an expenditure not incommensurate with the advantages gained, and within the limits available for improvements.

With regard to the criticism of the officials of the Calcutta Port Commission, Mr. Palmer and Mr. Petley, he must observe that in 1902, when the idea occurred to him of writing a Paper on the River Hooghly, he imagined that the lapse of several years would have removed the irritation and opposition aroused by his having followed the written instructions given him in preparing his Report of 1896, instead of complying with the suggestion, made to him at the outset, that he should not propose any works (which would have implied his belief that the river was incapable of improvement, and would have been highly prejudicial to the shipping interests), and by his disregard of the subsequent warning that any scheme of improvement he might offer would be strongly opposed; and he, therefore, applied to Mr. Petley for information and assistance for the preparation of the Paper, and received a reply precluding any further correspondence. When a few months later he ventured, in spite of this rebuff, to apply to the Commissioners, he received a similar reply; but, having in the meantime written to a higher quarter, on making a second application, the Commissioners sent him the printed sheets of surveys mentioned in the Paper. Consequently, if there was any small discrepancy between the Paper and the results of the most recent investigations, this must be entirely attributed to all particulars since 1896, beyond the printed sheets of surveys, having been withheld by the officials. With regard to Mr. Palmer's objection to the Author's statements about deterioration in certain places on the river, with the exception of Royapur, precisely the same views had been expressed in his Report, and not disputed by Mr. Apjohn and Mr. Petley in their joint Notes on that Report.[1]

[1] The Author presented copies of these Notes and his replies to the library of the Institution in 1897.

A written statement, indeed, by Mr. Petley, printed in the Report of the Luff Point Commission of 1904, contained the following sentence: "Again, in 1898 the same fear arose after the loss of the *City of Canterbury*, and a Specialist on rivers came out from England to study the question, and he was of opinion, after examining every available document, that the river was not deteriorating."[1] Though the date given did not agree, this could only refer to the Author's Report of 1896, and was inaccurate; for he had plainly pointed out under the headings "Deterioration at the Moyapur Crossing" and "Deterioration of the James and Mary Reach," that deterioration had occurred at these places, though the general condition of the river appeared fairly stable. As regarded Royapur, comparison of Figs. 14, 15, and 16, Plate 4, demonstrated that deterioration had taken place there; and Mr. Petley in the same statement said that the Royapur bar "was a very good one until 1901, when it silted up very considerably," though improving subsequently. The curves of best available depths on the Moyapur and Eastern Gut bars given by Mr. Petley in *Fig. 34*, seemed to indicate an improvement in depth since 1897, especially at the Eastern Gut; but the moderate improvement over the Moyapur bar might be attributed to the more rapid discovery of the development of better tracks, by more frequent soundings over the crossing; and at the Eastern Gut the number of sailing-tracks had been augmented, and a staff of surveyors permanently stationed there, which greatly facilitated the finding of the deepest course. This had been fully confirmed as being the cause of the apparent improvement, by Mr. Apjohn in the discussion. The statement about the Ninan bar in the Paper, which Mr. Palmer questioned, was based on the following paragraph in Mr. Apjohn's Note of the 22nd April, 1891:—"Captain Petley shows that previously to 1885 there is no record of vessels having been unable to cross the Ninan bar, and states that in October of that year it first showed signs of deterioration." In asserting that surveys of the river were made throughout the year, Mr. Palmer must have been fully aware that there were two kinds of surveys made of the river, namely, soundings over the crossings and bars for the river-notices to pilots, on behalf of the navigation at the shoalest places of the river—which soundings were necessarily carried out at frequent intervals throughout the year —and complete surveys of the river between Calcutta and the estuary, taken in the dry season at intervals, for the most part, of

The Author.

[1] "Report of the Luff Point Commission," p. 171. Calcutta, 1904.

The Author. some years, whose chief value consisted in indicating general changes in the river, and enabling their causes to be traced, with a view to designing works of improvement. Since writing his Paper, he had been informed that the foreshores and shore-lines of those complete surveys were only roughly put in from the soundings, which was borne out by the evidence given by Commander Jarrad, R.N., before the Luff Point Commission, and which explained the appearance of certain anomalies in comparing charts of different dates; and from an engineering standpoint, it was most important that the foreshores and shore-lines should be carefully surveyed for each complete survey, so that accurate information as to changes in width, as well as in depth, might be obtained. It was of course due mostly to these river-notices, as well as to the great decrease in sailing ships, the improved buoyage, and the arrangement of numerous river-marks, that casualties had so materially diminished, and that vessels of greater draught could navigate the river, as shown in the Table presented by Mr. Palmer. The solitary vessel drawing over 28 feet, however, had occupied 3 days in getting down the river. He had found that a discharge of 650,000 cubic feet per second past Calcutta at the period of maximum flow, would require a velocity of 9 feet per second, instead of 13 feet as calculated by Mr. Palmer. Reference was made by Mr. Palmer to the estimate of the cost of the works proposed by the Author in his Report, as given by Mr. Apjohn and Mr. Petley in their first Note, in which, by carrying down the training-walls to the depth reached by the scour round an isolated wreck in the James and Mary reach, and by raising them above high water, and adding protective works to the full depth of the river along the right bank from Shipgunj Point to Mornington Point and other charges, they managed to raise the cost of the low training-walls proposed, from 25¾ lacs of rupees to 174 lacs. When, in his reply to the Note, he protested against the raising of the training-wall above high water, involving greatly increased scour and the protection of the opposite bank, and against the scour round an isolated wreck being treated as a basis for the scour along a training-wall connected with the bank, they, in a second Note, shifted their ground, and proposed to increase the width of the training-wall similarly to the Maas jetties extending into the open sea, and to introduce the loss on exchange, so as to raise sufficiently the cost of works to be carried out in India with materials obtained locally. These Notes, at any rate, had served their immediate purpose, of making the works appear prohibitive in cost, and of deferring indefinitely any

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improvement of the river for navigation. It was satisfactory to learn that the officials at last contemplated taking steps for the improvement of the navigable depth over the shoals, with regard to which nothing had hitherto been done. Mr. Petley mentioned that the officers of the Commission were preparing their own schemes for improving the water-way between Calcutta and the sea, but did not indicate the nature of these schemes. If it was merely proposed to endeavour to deepen the channels over the bars by dredging, no objection could be raised to this course; for even if this work did not prove thoroughly effectual at the Moyapur and Royapur crossings, and especially over the bar of the Eastern Gut, as his investigations in 1896 had led him to fear—in which view Mr. Apjohn and Mr. Petley concurred—the dredger proposed to be purchased might prove very useful in the estuary; and dredging could only have a beneficial influence on the river. It appeared, however, from a Note by Mr. Apjohn about dredging in the Hooghly, dated 23rd October, 1903, and printed in the Luff Point Report, that he was in favour of the execution of the scheme shown in *Figs. 22* and *23*; and as Mr. Petley was in agreement with Mr. Apjohn in 1899 as to the merits of this scheme, it seemed possible that it was the scheme referred to by him. Before any such scheme was entered upon, which appeared in certain respects at variance with the principles of river-regulation, as so clearly stated by Mr. Keele, and could therefore only result in disappointment, it seemed most important that, according to the practice followed in England in difficult cases of river-improvement, an exhaustive inquiry should be held by a competent Commission into the whole circumstances of the case, for which it would be the function of the river-surveyors to provide the requisite particulars. By this means the various conflicting views could be carefully considered, and after thorough investigation and due deliberation, a definite scheme of improvement could be prepared, calculated to satisfy the reasonable requirements of Calcutta as a port.

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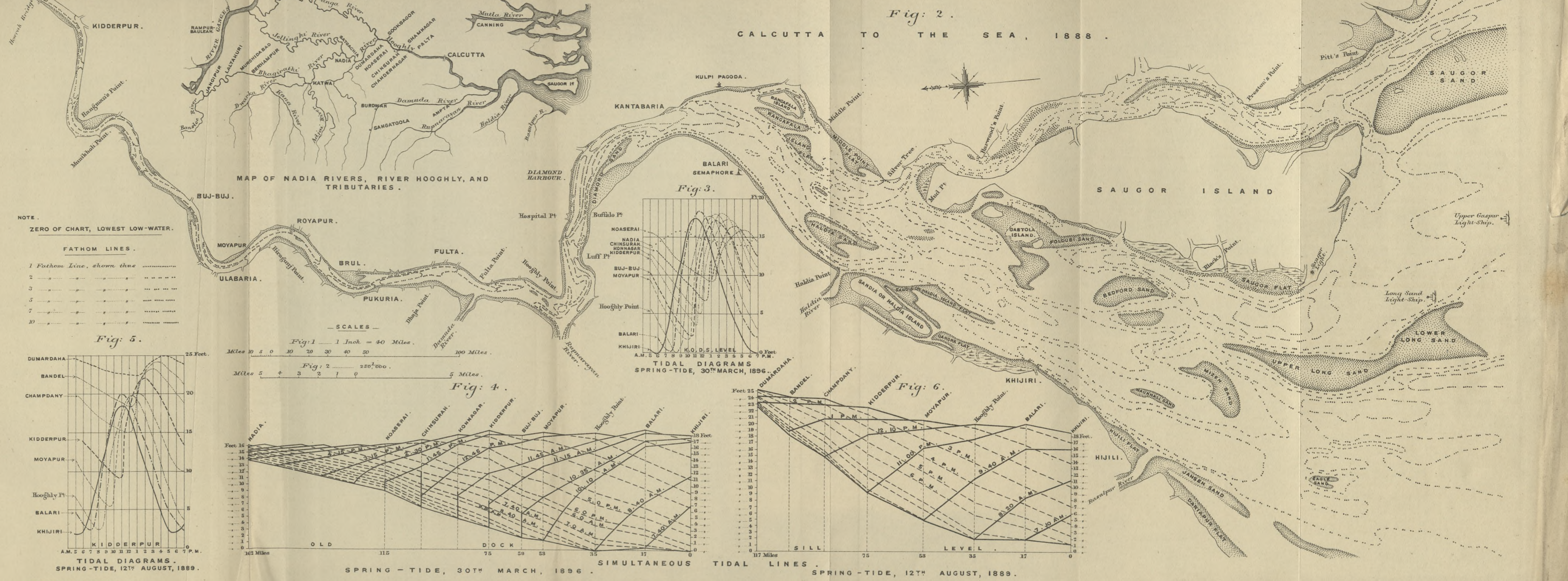
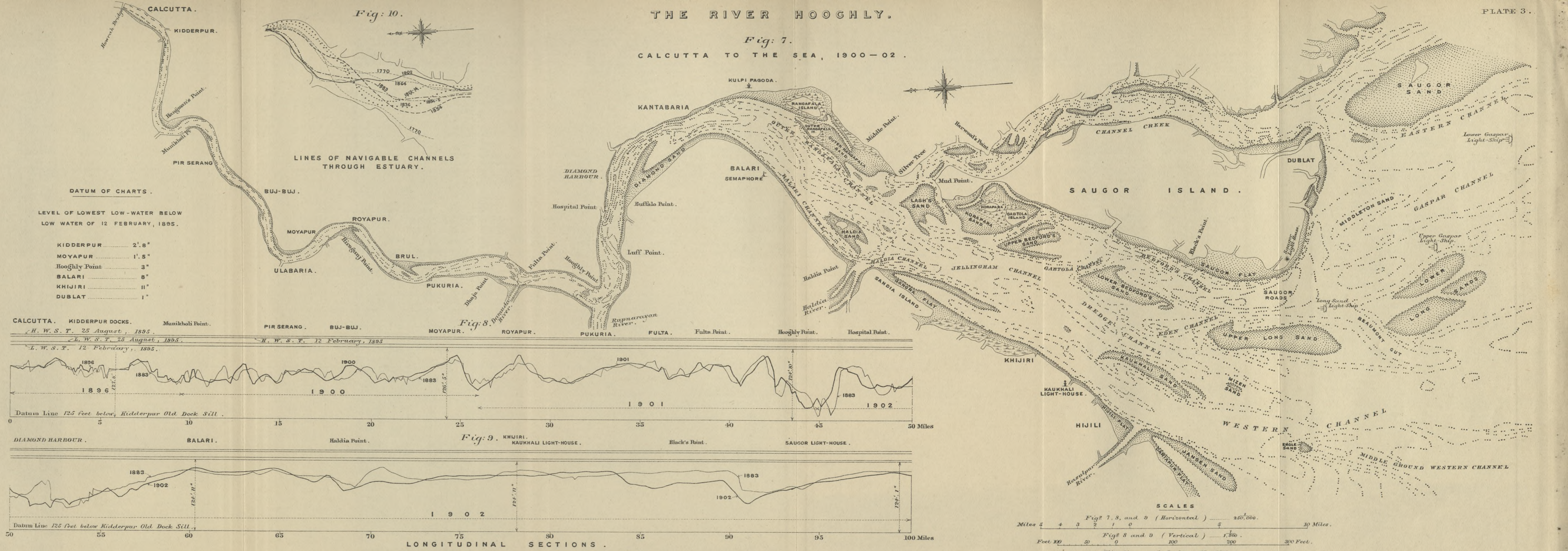
PLATE 2.

THE RIVER HOOGHLY.



THE RIVER HOOGHLY.



THE RIVER HOOGHLY.

L. F. VERNON-HARCOURT.

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