

would doubtless be somewhat reduced, owing to the reduction of tidal capacity in the estuary ; but this would be of less importance than in many other estuaries, on account of the ample depth existing there at present.

Mr. Vernon-Harcourt.

Correspondence.

Mr. P. CALAND observed that the Seine in so far resembled the Clyde, that on both, the trained lower river ended in an estuary opening into a bay of large superficial extent. The conditions on the Clyde were, however, much more favourable than those on the Seine, as according to the Report of Mr. Deas, of 1873, the last that Mr. Caland had received, the depth of water in the mouth of the lower channel of the Clyde had increased since the erection of the training-works, a result that had not, according to the Author, been attained in the Seine. In a scheme of improvement for the Seine, the interest of both Honfleur and Havre must be considered, which places were on opposite sides of the bay, and close to its mouth. In 1856 Mr. Caland was commissioned by the Netherlands Government to investigate, among other subjects, the condition of the Seine, and his Report, published on the 15th of October, 1856, contained the following paragraph:—"It appears to me that the river-improvement works commenced beyond the Amfard and the Ratier Banks, must be further extended if any useful result is to be obtained." At that time the true nature of the problem did not seem to have been apprehended in France, neither had any general scheme of river-improvement been formulated, and the works were carried out from above downwards (instead of beginning at the sea end and working upwards). The latter course might be explained by the existence of shoals at some distance above the mouth (the Traverse de Villequier and the Flac Bank); but in any case a general scheme for the improvement of the whole river might have been planned. It would then have been apparent that the river was very unduly contracted, and that to provide proper space in the trained-channel it should have been widened at the lower end. That the Estuary of the Seine had become decidedly shallower in late years was not, in his opinion, a matter of surprise. Formerly the sand and mud brought down by the river-flood was deposited in thin layers upon the ground outside the river-bed proper, whence it was carried seawards and dispersed by the waves during periods of storm and high flood-tides; but since the river-bed had been narrowed and deepened, the bulk of the transported material was

Mr. Caland. deposited beyond the end of the trained-channel as a compact mass in deep water, where it was no longer susceptible of being loosened by the action of the waves. On the Clyde, if Mr. Caland was not mistaken, extensive dredging operations had been carried out between the training-walls, which had not only prevented the formation of shoals seawards, but had increased the scouring-power of the lower river, with the results of increasing the depth of water in the bay as well as in the trained-channels. On the Seine, on the other hand, since the completion of the works, the deepening of the channel had been left to nature, that was, to the river itself.

As regarded the Seine, many points seemed to require further explanation. For instance:—Had the velocity of the tidal-current undergone any change since the improvement works had been carried out, and if so, to what extent? How far did the sea-water flow up the river now as compared with former times? What was the reason that the time of high-water and of the turn of the ebb was earlier at Havre than it used to be? That the latter result was due to the deepening of the channel seawards did not appear to be probable; most likely the cause was to be sought in the river itself. Another question of importance was:—Where did the action of the flood cease? In 1856 the tidal-limit was at Poses about thirty-three hours distant above Havre, and it would be matter of the greatest interest to know whether there had not been a change in that limit. Mr. Caland thought there might very well have been. The Author considered the point of principal interest at present to be the improvement of the river between Berville and Havre. As far as he was able to judge without further investigation, the plan proposed by Mr. Lavoinne in 1882 was generally preferable to that of the Author. He would be inclined to carry the left training-line farther out into the river, and to lengthen the harbour of Honfleur, while on the right line he would follow Mr. Lemire's plan and curve, bending it to the eastward of Havre, in order to prevent a possible widening of the stream in front of the latter port, and consequently diminishing the depth at that place.

The width of the mouth of the channel on the Author's plan was far too great, and the funnel-shape necessary in every lower river subject to tidal ebb and flow appeared to him to be better provided for in Mr. Lavoinne's scheme. Whether a widening of the channel above Berville might not result from the works proposed could not be determined without further investigation. True, the difference in width between the proposed mouth and the

outer ends of the training-walls was very considerable, but it must be borne in mind that before the river works were executed the like difference existed between the mouth and the river at, for instance, Vieux Port and Aizier, which places, having regard to the entire length of the lower river, were not so very much higher up than Berville.

Mr. CAMÉRE wished to acknowledge the value of the Paper, which constituted a complete and interesting monograph of the basin of the Seine. He would limit his remarks to one or two questions treated of in the Paper, and which he hoped to render more clear. The Author, at p. 230, expressed the opinion that, "the variety of types adopted within one river-basin has been due to the desire of the engineers in charge of the different sections to devise some new and improved type, and not to the special adaptability of each type to the localities in which they are situated." As the best means of combating this opinion, Mr. Caméré proposed to give a succinct history of these different types of weir. The earliest artificial improvement of the rivers of the Seine basin, and which went back several centuries, consisted in passes generally constructed in dams of wood and stone, put down for the use of mills and factories. These openings were closed by beams or needles. To these primitive passes, difficult to manœuvre, and occasioning considerable waste of water, succeeded (notably on the Yonne towards the end of the last and the beginning of this century) passes with side-walls and aprons of masonry 26 feet wide, closed by needles bearing at the top against pivoting-bars. Later on the width of the passes established on the River Yonne was increased to 40 feet, and the supporting bar superseded by a cable, stretched or slacked, as needed. The danger and difficulty to the barges in passing through these narrow openings, naturally led the engineers to widen them, and it was this that led Mr. Poirée, in 1834, to increase the width for the Basseville pass to 72 feet, and to support the needles against frames spaced at intervals between the side-walls. Such was the inception of the type of weir which bore the name of the engineer in question, and which, in combination with the employment of sluices, rendered the navigation of the Yonne and of the Lower Seine incomparably superior to its previous state. Notwithstanding its good qualities, due to the fewness of parts and the simplicity of its manœuvring, the Poirée dam manifested the following faults when proposed to be applied for greater heights, either for diminishing the number of reaches, or for increasing the depth of water:—the obligation of applying needles and frames of unmanageable size and weight; the necessity of

Mr. Caméré, combining, with dams of this system, overfalls of considerable extent, and therefore costly: the want of having recourse to incessant manipulation, in order to prevent the service-footway from being submerged, the latter rendered probable by the small height above the pool, manœuvres that might even become impossible on the occurrence of a sudden and brisk rise of the river. The impossibility of keeping the needles sufficiently watertight to maintain the normal depth above the weir, by reason of the flow of the river becoming insignificant. It was to meet these disadvantages that the authorities adopted the Chanoine system for the weirs to be constructed on the Upper Seine in 1860. Nevertheless, experience soon showed that the service of the Chanoine weirs presented serious difficulties, and that they were liable to fall down unexpectedly, thus entailing, by reason of the sudden alteration of depth, grave inconvenience to the navigation. As regarded Mr. Desfontaine's drum-weirs, they did not properly constitute a complete system applicable to navigable passes, but rather allowed of the formation of an overfall of extent sufficient, having regard to the ease of manipulation, to regulate the depth without having recourse to the incessant opening and closing of the deeper weirs, and even to afford valuable assistance in the manœuvring of the latter. In this way drum-weirs had been applied between 1857 and 1867 to the overfalls of the Marne weirs, in which the deep passes were closed by Chanoine shutters. The end kept in view by the authorities in installing on the Upper and Lower Seine, as well as upon its principal affluents, dams of the Poirée or of the Chanoine types, was to give to these rivers a depth of 5 feet 3 inches. In so far as the Lower Seine was concerned, it was soon found that this depth, which was being achieved under the law of the 31st of May, 1846, no longer responded to the growing requirements of the navigation, and in 1861 it was decided to put up new dams of the Poirée type between Paris and Rouen. The inquiries undertaken by Messrs. Belgrand, Krantz, and de Lagrené, having led those engineers to think that increased expenditure necessitated by substituting a depth of $10\frac{1}{2}$ feet for one of 6 feet 6 inches would not be excessive, and the Admiralty, to whom were entrusted the preliminary studies relative to these proposals, having decisively pronounced in favour of the greater depth, the latter was adopted by the law of the 6th of April, 1878. To avoid multiplying beyond reason the number of pools, it was necessary, in order to obtain a depth of $10\frac{1}{2}$ feet, to employ dams of a minimum height of 13 feet. Although the Poirée system had never yet been employed for such heights, it was adopted by the authorities in default of any systems

of well-ascertained superiority. It was, furthermore, the type of Mr. Caméré. dam prescribed in 1876 for application at Port Villez. Being entrusted with the construction of this weir, he had early come to the conclusion that this enlarged type of Poirée dam went beyond the limits of regular working, not only by reason of the damage that it was to be feared might happen, when being lowered, to frames 18 feet high and weighing nearly 2 tons, but also on account of the difficulty to be anticipated in handling the needles, which were proposed to be nearly 8 inches square.¹ These uncertainties so impressed him that, having to design several other dams for the Seine, he hesitated to adopt a type in which he had so little confidence.²

Such were the reasons leading him to seek for a type of weir in which all the shutting parts could, in times of flood, be raised above water-level, and in which the obstruction was compatible with deep water in the pool above, a system having the weir at Poses as a first example, and which was described in the Paper (p. 234). At Poses the fall was not less than 21 feet, and the pool constituted by this dam was 26 miles long. The dam was opened on the 23rd of September, 1885, and had stood the test of the exceptional floods of the Seine in the winter of 1885-86. Its working had left nothing to be desired, and it had proved one thing that deserved to be recorded, namely, that no system of weir with parts lowered on the bed of the river could have been capable of satisfactory working under such conditions as had occurred at Poses. As long as it was only a question of constructing weirs of small fall, the lowering was accomplished before the floods had reached the lower pools, and therefore before the water had brought down much detritus. These conditions did not obtain at Poses, where the pent-up water attained almost to the height of great floods. In this case the quantity of *débris* of all descriptions—grass, branches, snags, whole trees brought down and arrested by the dam—was such as would have rendered almost impossible the working of any weir whose main parts were under water, especially as regarded the frames. Notwithstanding

¹ In the first design it was proposed to work these needles mechanically; as carried out they had been replaced by the Caméré hinged curtains.

² Since the opening of the Port Villez dam in 1880 numerous breakages and deformations of the frames had occurred, caused by their bedding on stones and stumps brought down by floods and deposited on the sill. It had further been proved that no moving of the frames could be easily accomplished, even with the weir open, when once the water in the lower pool was 1 metre (3 feet 3 inches) below that in the upper one.

Mr. Caméré. the amount of the obstruction accumulated against the Poses weir before it was raised ¹ on the 15th of December, 1885, the opening was effected without difficulty by ordinary means, and without necessitating recourse to the special machinery provided in case of emergency.

The brief history given by him of the Seine weirs would show that the aim had constantly been to keep pace with the demands of the constantly-growing traffic. If engineers still hesitated to pronounce on the rival merits of the Poirée and Chanoine systems as adapted to slight falls, they would nevertheless not doubt that such types were not suited for giving the Lower Seine a depth of $10\frac{1}{2}$ feet, and also they would perhaps come to the conclusion that the Poses weir, in solving this question, had furnished a practical example of a movable dam of great height, and affording every security for working.

The Author's figures, at pp. 233, 235, in his comparison of the cost of the weirs at Poses and Port Villez, needed to be explained, in order that an exact idea might be had of the expense of such structures. At Port Villez, as at Poses, a solid foundation was only found at a great depth, below the beds of gravel and sand forming the river bottom. In order to be beyond the influence of infiltration it was decided to make the Port Villez foundations 24 feet deep; those at Poses were nearly 29 feet below the surface of the sills of the deep passes. These very costly foundations evidently ought not to be considered inherent to the system, and the following figures would give a juster idea of the cost per lineal metre under ordinary conditions, say with foundations $6\frac{1}{2}$ feet deep:—

—	Port Villez.	Poses.
Extraordinary foundations	£280	£280
Masonry of the sills, piers, &c., including the metallic fittings of the sill }	160	£100
Metallic superstructure, and curtains . .	100	120
	— 260	— 220
	£540	£500

or £163 7s. and £151 5s. per lineal foot respectively; but inasmuch as the Port Villez weir only retained a pool 15 miles long, whereas that at Poses retained one 26 miles long, the advantage in respect of result was greatly in favour of Poses.

¹ The amount of this *débris* could be estimated from the photographs exhibited at the Meeting.

At p. 236 the Author expressed the opinion that, seeing the smallness of the fall designed for Port-Mort, recourse might possibly have been had to a more economical type of dam for that site. Notwithstanding the slight fall (8 feet 9 inches), the height of this weir was not less than 18 feet. Now the inconvenience that had been experienced at Port Villez from the employment of high and heavy frames had naturally led Mr. Caméré to reproduce the Poses type at Port-Mort, of which the good working was assured, and which also presented the advantage of being readily adapted to a greater height should the future requirements of the navigation make it advisable. The footway in the Port-Mort weir, like that at Poses, had been made 3 feet 3 inches above the height of the water upheld, in order to allow later on of a lengthening of the hinged curtains, or of the establishment of small supplementary sluices worked by hand, and so augmenting the height of the water by 20 or even 30 inches, which would easily allow of a depth of 13 feet being maintained in the Seine without the least hindrance to navigation. The facility of raising characteristic weirs of the Poses type was an important advantage which ought evidently to be carried to its credit.

Mr. J. DE COENE presented to the Library, as a contribution to the question under discussion, an abstract of his evidence given before the Technical Commission of the Seine, nominated by the French Minister of Public Works; also a report of the Belgodutch Commission, nominated in 1866 to consider the scheme of a weir for the East Scheldt.

From the former of these documents it would be gathered that Mr. de Coene favoured the narrowing of the outlet of the river, the conservation of a vast interior estuary forming a powerful reservoir; and the construction of a new and completely-sheltered entrance to Havre, of such a character as to give deep-water access to that port at all states of the tide. He desired to draw attention to the views as set forth in the accompanying documents of Mr. Partiot, Inspector-General of Roads and Bridges, who had occupied for several years the position of Engineer of the Maritime Seine. Mr. Partiot had executed part of the estuary works, which had given such splendid results, insomuch that Rouen, formerly accessible only to vessels drawing 10 feet, now received those drawing from 20 to 23 feet, and that for sea-going ships freight and assurance at Rouen were the same as at Havre. The present improved state of affairs gave great value to Mr. Partiot's opinions. Mr. de Coene would remark upon the movement of the alluvial matter brought into the estuary by the flood-

Mr. de Coene. tide, and afterwards carried away to great depths in the sea by the ebb. The Author's figures were significant on this head. In 1834, before the embankments existed, the capacity of the estuary below the zero of the marine charts was 433,000,000 cubic yards; in 1854 it was 387,000,000 cubic yards; in 1869 (the embankments having been completed in 1860) it was 490,000,000 cubic yards; in 1880, 441,000,000 cubic yards. That was to say, in 1880 with the embankments the estuary was more capacious than in 1834 without them; while in 1869, in spite of the embankments, and contrary to the opinions of the Havre engineers, the estuary was deeper than it had ever been. All rivers with narrow mouths had deep channels, all those with wide mouths had bars. There was no exception. The Mersey formed an example, as did the Seine at present. It seemed therefore to Mr. de Coene that the Paper was not complete as regarded the estuary. The Author had omitted to mention Mr. Partiot's project, which had been made known to him at the Rouen meeting of the French Association, and which offered a solution of the problem of improving the mouths of tidal rivers. Of all examples the most remarkable was that of the Humber, which had a very deep channel of great width, owing to the narrowing of the estuary. That was what engineers should strive to attain. The Author seemed to have relied too much on official information. He saw the subject from one point of view only, and had not treated it with sufficient breadth, but had kept to the beaten track. The comparison of the accretions and erosions of the estuary was a detail, an important one doubtless, but not one suggesting a general law of evolution.

Mr. de Coene ventured also to cite the Belgo-Dutch report. The conclusions arrived at were worthy of remark. It was laid down, for instance—first, that the ebb of a tide carried off more than the flood brought in; secondly, that all efforts should be concentrated in the current of a single channel. Facts supported these conclusions. That was the solution sought in the case of the Seine. In his communication to the Industrial Society of Rouen, he had considered the estuaries of all the great rivers—Gironde, Scheldt, Elbe, Tagus, Foyle, and Tay—and the comparison had led him to a conclusion which had not once been falsified. In a summary study he had lately made of the river Mersey, he expected to arrive at the same conclusion, the realization of which would be a great benefit to Liverpool, where access was impossible at low water.

Mr. Fowler. Mr. JOHN FOWLER (of Stockton) observed that some of the Author's remarks as to the effect produced by the works on the tidal section

of the Seine seemed to be open to objection. The results which had followed the works on the Seine were akin to what had followed similar works carried out in a corresponding manner in this country. Experience proved that accretion followed training-walls or groynes, whether transverse or longitudinal, the accretion proceeding with more or less rapidity according to the quantity of solid matter contained in the water, and ultimately rising to within a foot or two of the height of the training-works. When the foreshore was narrow and the lateral currents were stopped, the surface assumed a curved slope from the shore, but when wide the surface was level as shown on Plate 4, Fig. 7. The works on the Seine had been carried above average high-water level, and probably reclamation was the primary object in carrying them so high. Chalk was not a good material for the purpose, but by repeated making up it was more likely to stand at one-quarter or one-third tide than at full-tide height. At one part of the Tees where the depth of sand exceeded 40 feet, and the current at unusually high tides was over 4 miles per hour, the wall had been made up four or five times; and whilst the average cost of the walls was 28s. 6d. per lineal yard this part cost £5 5s. The accretion beyond the ends of the training-walls was less than might have been expected, considering the large quantity of soil which had been removed from the channel. Between the training-walls the section on Plate 4, Fig. 2, showed deepening ranging from 10 feet to 36 feet over a length of 28 miles, and an average breadth of $\frac{1}{4}$ mile; so that taking the average deepening and half width there would be more than 80,000,000 cubic yards of soil removed, some of which would no doubt find a resting place round the ends of the training-walls, but the greater part would be carried downward to the lower estuary. No doubt if the training-walls were of full-tide height to the end, permanent accretion would take place under their shelter. It appeared, however, from the Tables given in Appendix II, that the tidal capacity of the Lower Estuary had been subject to great variation prior to the commencement of the works, and that its condition in 1883 was nearly 11,000,000 cubic yards better than in 1853. It also appeared that between 1875 and 1880 accretion took place at the rate of 11,000,000 cubic yards per annum, whilst between 1880 and 1883 it was under 650,000 cubic yards per annum, and probably it had now ceased. These fluctuations were common to all sandy estuaries, and they often extended over long periods in one direction.

In 1762 the sandbanks at the mouth of the Tees and the depth (4 feet) on the bar were almost exactly the same as in 1862. Persons unacquainted with the earlier chart jumped to the con-

Mr. Fowler. clusion that the decrease in depth was due to accretion which had followed the early works of the Tees Navigation Company. No mention was made of any deterioration in the channel beyond the training-walls, and therefore it might be inferred there was none arising from the accretion.

The Author assumed a parallel between the works in the Seine and those proposed for the improvement of the Mersey two years ago. The works proposed in the Mersey, however, differed in three important points from those carried out on the Seine. The training-walls did not terminate in the middle of a sandy estuary but beyond. The training-walls were not proposed to be of full-tide height, but the average height of the sandbanks. The channel was not to be formed by scour but dredged out; instead of 80,000,000 or 100,000,000 cubic yards being driven down to the lower sandbanks, more than 16,000,000 cubic yards of material were to be lifted out of the estuary by dredging. The outer sands at the entrance of the Mersey were entirely separate from the sands in the upper estuary. The narrow channel between Liverpool and Birkenhead gave the direction to the incoming and the outgoing current. Alterations in the form or height of the sandbanks in the bay did not affect the upper estuary, neither did alterations above Liverpool affect the channels in the bay, the tidal capacity remaining the same. The question at issue was, would low training-walls, such as were proposed in the Mersey and had been carried out in the Tees, encourage accretion above their height? The works in the Seine, being so different in character and situation, could give no answer; the works in the Estuary of the Tees showed that they would not.

Mr. Garlick. Mr. E. GARLICK remarked that the training-walls sketched out by the Author in the Estuary below La Rille would, from their convexity, evidently throw the channel from side to side of the new estuary, instead of keeping it always acting in one and the same position, and in a direct course to the sea. At Honfleur the distance between the proposed walls was $1\frac{1}{2}$ mile, and at the mouth of the estuary $5\frac{1}{2}$ miles. In the new wide estuary within the training-walls the channel would wander about without improvement, neither kept to Honfleur nor to Havre. The training-wall 6 miles in length, from Honfleur to Villerville Point, did not exhibit any utility worth the expenditure, for it was parallel with the present shore, apparently exercising no new tidal influence. From an examination of the plan, Plate 4, Fig. 8, he thought the proposal might not injure the navigation down to Honfleur, because there was a possibility of the channel generally remaining

on that side of the estuary; being then at Honfleur, there was Mr. Garlick's little probability of it making across from there to Havre. But what would be the effect at Havre when the Author's north training-wall was put in, and the Pointe du Hoc deep, which extended up the Estuary for 7 miles, had been stopped up close to Havre by this north training-wall; and when the channel of the Seine had taken, and for a long time kept, a southern course, and all along the north training-wall the reclamation behind the wall was completed, and the accumulation of sand had extended over that wall into the Estuary, as there was every probability from the curvature of the line of wall and wide estuary it would do? Would not the effect on the navigation of Havre be ruinous?

Professor J. GAUDARD had been greatly interested in the question of movable weirs, having recently compiled a notice on this subject for the Bulletin de la Société Vaudoise des Ingénieurs et des Architectes. The systems in use on the Seine suggested the following conclusions:—For weirs frequently raised and lowered a footway was generally adopted; now, from the moment that it existed and could render support to the needles, this simple attachment, sufficient for small heights, supplanted the Chanoine shutters. These shutters were still appropriate for navigable passes, but when their height exceeded 10 feet, it was advisable to replace the winch-barge by a movable footway, and hence arose the question of seeking to use the frames (*fermettes*) as supports for the wall of the dam, and so dispensing with the props and trestles of the Chanoine system. This was what had been done by Messrs. Boulé and Caméré; the needles being found too heavy, these engineers had substituted the more-easily managed curtains, constituting formidable competition with the older shutters. The same idea seemed to have inspired Mr. Pasqueau, in his modification of the Chanoine system on the Rhone. The Tavernier system, with an upper fixed bridge, was more ambitious than those with the movable footways. It had been recommended for the Rhone by Mr. Pasqueau, on account of the stones and gravel brought down by that river impeding the lowering of the frames on the bed. This type of weir, in fact, did not allow of any delicate parts lying on the river-bed. There only needed a sill to support the footings of the uprights of the weir. Now, with the Caméré curtains it would not be difficult to disencumber this sill. It would suffice simply to raise the bottom of the curtains a little, to allow of a sufficient rush of water to clear away any deposit. The Poses weir, opened in October 1885, under the direction of Mr. Caméré, had successfully borne the test of the severe floods of the winter 1885-86.

Professor
Gaudard.

Professor
Gaudard.

As regarded the estuary of the Seine, the Author submitted a carefully-studied profile for the extension of the embankments, leaving scope for dredging an entrance to Honfleur, which was justified by the power and economy of modern dredgers. Until some time ago the authorities at Honfleur were not above certain modest expedients, sufficient for the time being. They employed osier baskets, anchored by ropes to submerged boulders, in such a way that the flood-tide overturned each basket, and by making it oscillate and by eddying round it, scoured out a hole into which the mooring-boulder sank deeper and deeper. These floating obstructions therefore induced scouring without reefs, as did fixed piles. With eighty baskets, spaced 16 feet apart on a sand-bank, a trench 650 feet long, 4 feet 2 inches deep, and from 16 to 20 feet wide, had been obtained in less than two days, which trench had afterwards been deepened by flushing. This expedient was only successful in currents running from 3 to 4 knots an hour, where, on the other hand, dredging would be impracticable. It had further been proposed to inject air through tubes perforated at the bottom, in order to break up banks where consolidated.

The motion of the tide removed any bar formed of fluvial sediment, not only because it diluted and easily dispersed such material, but because, by mingling with the river-water, it communicated its saltness, and consequently density, to the latter. In a tideless river, on the other hand, it was probable that the heavier sea-water was confined more or less to the lower parts of the estuary. The river-water, in spreading over the surface and losing its forward velocity, allowed the suspended matter to settle. But the example of the Seine showed that, in default of fluvial sediment, there yet remained the sands coming from the sea to be grappled with. The great means of removing these was still the pendulum-like sweeping of the tide, but inasmuch as the tidal broom swept in two directions, it was necessary that the ebb should have greater force than the flood. Velocity was required sufficient to remove sand-banks, without at the same time being dangerous for navigation. In default of a sufficient excess of power of the ebb, the estuary would get choked up by the sand-bearing waters during storms, depositing their burden in places where the cross-action of contending waters destroyed their velocity; and it necessarily required more power to uplift and impart motion to matter once deposited, than to keep it in motion before deposit had occurred. Thus, the Loire between St. Nazaire and Nantes showed a zone where this action and counter-action was indecisive, and where the anchorages filled up in the most persistent manner, albeit good depths were

maintained in the estuary, which was more contracted than that of the Seine.¹ The preponderating action of the ebb was assured by the addition to it of the fluvial current while the flood lacked that element. By the same token, it would appear that the smaller the volume of the flood, the greater would be this differential action. Nevertheless, it was well known that the volume of oscillating water was of importance for deepening the channel, although there was no occasion to be anxious about the loss of area for expansion by the cutting off of the spaces behind the embankments. The example of the Humber showed that tidal capacity did not suffer from the reclamation of land, so long as a countervailing gain existed in the increased depth of the channel. Now it was known how greatly the Seine embankments had assisted the flood-tide, and allowed it to ascend higher inland. The only fear that need be entertained was, that at the period of low-river, when the latter opposed but little resistance, great storms might act occasionally and partially to choke up the estuary, and that, between whiles, the ordinary movement of the tides might not have sufficient power to restore the normal depths. If that occurred, there remained (were it allowable to think of it) an extreme expedient. It was to induce a torrential reflux—a reverse storm-wave; to produce here what had been done on a smaller scale, yet not without serious difficulty, at the port of Honfleur, namely, to organize a flood by the retention of a spring-tide, temporarily imprisoned by a powerful movable weir, and suddenly released after a certain fall of the tide, navigation being suspended, and banks and other works made strong enough to resist the sudden impulse. It was, however, to be hoped that success would be obtained by less vigorous, and perhaps impracticable measures. On the other hand it was proposed to protect the roadstead by an external embankment, which would stop the accumulation of sand from waves and storms. The idea of scouring by retention and sudden release really meant only the increasing at proper times of the most powerful agent already existing. Floods disencumbered and deepened the channel. The same occurred at the first of the neap-tides, when the river rejected the excess of water which it had accumulated during the period of springs, and the ebb, acquiring more force, deepened the channels seaward. The ebb made the channel; the flood, on the other hand, overturned and equalized such irregularities.

It was a curious fact that extensive estuaries were found where

Professor
Gaudard.

¹ *Annales des Ponts et Chaussées*. 1878. 5^e Série. Tome xvi. p. 563.

Professor they were of no use. He referred to the glacial rivers, the upper Gaudard. Rhine and Rhone, in the Lakes of Constance and Geneva. These waters, denser by their low temperature and the sediment they contained than those of the lakes, had a tendency to plunge under the water of the lakes, rather than to disperse themselves over the surface. Recent soundings had shown that, far from causing bars, their action had traced, for a length of several kilometres, profound ravines in the lacustrine depths.¹

Sir Charles
Hartley.

Sir CHARLES HARTLEY, K.C.M.G., having had occasion to study the characteristics of the Seine as a navigable stream, in the preparation of his lecture to the Institution on "Inland Navigations in Europe,"² could testify to the accurate description given by the Author, of the chief features of the Seine, and of the results which had followed the efforts made up to this time to improve its condition as a navigable highway. So far as regarded the canalization of the river between Montereau and Paris, he had no remark to offer, save that, from his own observation, the locks and weirs which had been established in that part of the river since 1860, had effectually overcome all the difficulties and delays which formerly attended the tedious system of intermittent navigation, created by artificial floods of necessarily short duration. In considering the improvement of the navigation between Paris and the sea by the valley of the Seine, three separate modes of treatment at once presented themselves to the mind of the hydraulic engineer:—1. The deepening of the bed of the existing water-way by training-works and by dredging; 2. The construction of one or more lateral canals on one side or other of the Seine valley; and 3. The canalization of the river from Paris to Rouen, and thence by a well-trained open channel to the sea. Each of these plans had been attentively studied by French engineers long before the execution of works of any description was decided upon.

The first serious project, after Mr. Cachin's, was that of Mr. de Lamblardie, who, in 1773, proposed to cut a canal on the right bank of the Seine between Havre and Villequier, at an estimated cost of £400,000. This canal was designed to have a length of 31 miles, a width of 121 feet at the water-line, and a depth of 20 feet. Half a century later, Mr. Berigny was charged by the Government to study the numerous projects which had been publicly brought forward up to that period for the improvement of the Lower Seine, and, having done so, he reported in favour of

¹ Bulletin de la Société Vaudoise des Ingénieurs et des Architectes, 1885, p. 53.

² The Theory and Practice of Hydro-Mechanics. Session 1884-85. p. 101.

Mr. de Lamblardie's project. He found it necessary, however, to quadruple the sum originally estimated, owing to the great changes which had taken place along the site of the canal, and to the great advance in wages that had arisen since the first estimate was made.¹ In 1825, a Government Commission, of which Mr. de Prony was the chief technical member, recommended the execution of a grand project, based on new surveys and data of every available kind, for the construction of a maritime canal between Paris and Havre. The length of this canal was designed to be 182 miles (120 miles from Paris to Rouen, and 62 miles from Rouen to Havre); its width, 65 feet at the bottom, and its depth 20 feet. The estimated cost was £8,600,000. In 1830, the execution of this magnificent scheme was arrested owing to revolutionary troubles, and was soon afterwards completely lost sight of; partly because the contemplated expense was so enormous, and partly on account of the rage for the construction of railways, which, spreading throughout France immediately after the first introduction of the locomotive into that country, caused all other public works of magnitude to be neglected for a term of many years' duration. Owing to these circumstances, it was not until 1846, as the Author had related, that energetic steps were taken to improve the Seine below Paris. Since that period to the present day, large sums had been spent annually on works connected with the canalization of the river between Paris and Rouen; but in the lower or tidal part of the river, the expenditure on the embankment-works ceased altogether in 1870.

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With regard to the canalization between Paris and Martot, by means of which a permanent depth of $10\frac{1}{2}$ feet was on the eve of being obtained, as contrasted with a depth of only 4 feet forty years ago, he should like if possible, to have it explained by the Author, how it happened that the establishment of a depth of $13\frac{1}{2}$ feet, the intended ultimate depth between Rouen and the St. Aubin lock, near Martot, was not aimed at between Rouen and Paris in the first instance? According to the longitudinal section given by the Author, the cost of obtaining an additional metre in depth in the upper ponds by dredging would have been trifling, in comparison with the immense advantages which would have been gained by the admission of vessels, drawing 13 feet instead of 10 feet, into the very centre of the French capital.

The question of resuscitating the scheme of 1825 for the construction of a ship-canal between Paris and the sea could not be

¹ Navigation Maritime du Havre à Paris. Par C. Berigny. Paris, 1826.

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profitably discussed in the absence of special information relating to the drainage-levels of the Seine valley; and, moreover, he fully agreed with the Author that it would be wise to wait and see whether the greatly improved waterway between Rouen and Paris, now nearly completed, would not suffice to supply all the requirements of Paris, before attempting to burden the State with an enterprize of very doubtful financial advantage.

The Author's account of the training of the river from La Maileraye (51 miles below Rouen) to Tancarville, La Roque, and Berville, was highly interesting and instructive. The total cost of the work (£1,200,000) including the estimated repairs of the walls, had been small, considering the great benefits the work had conferred on agriculture and commerce. The embankments, although stopping far short of the point designed in 1845 by Mr. Bouniceau, had already accomplished the following results. The minimum navigable depth between Rouen and Havre at high water, at neap tides, had been increased 8 feet, or from 10 feet up to 18 feet, thus allowing the passage of vessels of 2,000 tons at the present time as compared with only 200 tons in 1845. In 1881 the shipping trade of Rouen had increased to 1,472,215 tons, or to treble the tonnage frequenting the port previous to the improvements; and, lastly, 25,000 acres of land had been reclaimed, the value of which was estimated at a much larger sum than the total cost of the works. These substantial advantages, combined with the fact that the bed of the "Thalweg," or centre of the navigable channel, was now lower rather than higher than formerly, were amply sufficient in the opinion of Sir Charles Hartley to justify the embanking of the Seine, even if it stopped short for ever at Berville. He could not therefore agree with the Author that the example of the Seine was a warning to the authorities of other estuaries such as those of the Mersey and the Ribble. It was no doubt unadvisable to terminate training-walls in the middle of a sandy estuary if means could be found to extend them to the sea; but the example of Mr. Bouniceau's uncompleted project alone would serve as a salutary warning if it could be proved that the great improvements of Berville had only been accomplished at the expense of the navigable channel lower down. It was not his intention to refer further either to the Mersey or to the Ribble, being conscious that his ignorance of the principal elements affecting the regimen of the estuaries of those rivers would render any remarks he might offer thereon entirely valueless.

As in all river-works, it would no doubt be possible, judging by

results, to improve on the plan that had been executed for the improvement of the Seine below La Mailleraye. Apparently, for instance, it would have been better to have constructed the walls with greater solidity, and to have widened out the channel more rapidly as it approached Berville, for in the first case the very onerous cost of maintenance, which had been so much neglected, would have been greatly diminished, and in the second, not only would a greater volume of tidal-water have been admitted, but a much better start could have been made at Berville, as the Author had pointed out, for the prolongation of the walls to the sea. Moreover, the too great contraction of the tidal-space had given rise to undue scour, a circumstance which had abnormally deepened the artificially embanked channel over long distances at the expense of the tidal-capacity of the estuary, although not of its navigable channel. The total amount of scour had been enormous, for, taking the longitudinal section as a basis for calculation, the average lowering of the bed of the trained channel had been about 18 feet. Thus the length of channel being 28 miles from La Piette to Berville, and its average width 440 yards, the amount of silt and sand scoured away and carried into the estuary was 130,000,000 cubic yards, a quantity, it might be remarked in passing, nearly equivalent to, though of course in a great measure independent of, the accretion of 137,000,000 cubic yards, which, according to Mr. Estignard, had been deposited during the period 1866-75, from the end of the training-walls to the meridian of Honfleur. Between the latter and the meridian of Cap de la Hève, according to Mr. Lavoinnie, the changes which had taken place during the period 1834-83, had resulted in an accretion of 76,239,220 cubic yards, and in an erosion, principally to the south of the Amfard bank, of 20,772,000 cubic yards; and, in connection with this statement, it should be remembered, although a close comparison of old with recent surveys would lead many experts to form a somewhat different opinion, that both Mr. Lavoinnie and Mr. Vauthier (who had carried his investigations for upwards of a mile to the west of Cap de la Hève) agreed in deducing from their Tables, in respect to the outer estuary, that the alterations in capacity by successive accretions and erosions, resulted from variations in the influence of the natural phenomena producing them, and that these changes have no apparent connection with the great alterations which have taken place in the upper estuary.

It ought further to be noticed in connection with the outer estuary, that Cap de la Hève and Pointe du Hoc had always been movable points, the first being continually destroyed by the sea,

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With regard to the effect of the works on the tidal flow, Mr. Lavoinne pointed out that the duration of the ebb-tide having been reduced from nine to seven hours above Berville, the velocity of the outflowing current had been considerably augmented, not only between the walls but for a considerable distance below them. He also referred to the advantage of the waters being driven back higher up stream than formerly by the flood-tide, and to the level of low-water at Rouen being about 1 metre lower now than in 1846—results which compensated in a considerable degree, for the great diminution of tidal-volume passing down the estuary. With regard to the present condition of the estuary below Berville, he further remarked that its contracted width, owing to comparatively recent deposits, had also contributed to increase the velocity of the ebb-tide; and that in this way the deposits had played an important part in maintaining and slightly increasing the original depth of the channel. He did not omit to add, however, that the frequent shifting of the navigable channel between the termination of the walls and Honfleur was still a source of difficulty and danger to shipping, especially in foggy weather, and that the condition of this part of the estuary urgently called for speedy redress.

The action of the training-walls in deepening the river between La Mailleraye and Berville (aided by dredging where, as at the Meules bank, the bed of the river was more or less solid), combined with the result of a long series of investigations relative to the regimen of the estuary, induced Mr. Lavoinne to recommend the completion of Mr. Bouniceau's original project as far as the site of the south wall was concerned; to modify the position of his proposed north wall by reconstructing it on a greatly widened out line between Tancarville and Berville; and thence to prolong the north wall on a line gradually widening from 4,000 feet at Berville to 8,000 feet at Honfleur, and to 13,000 feet opposite Havre; as compared with Mr. Bouniceau's 2,000 feet, 4,000 feet, and 7,000 feet at the same points respectively. In Mr. Bouniceau's project it was calculated that the proposed great contraction of the estuary

between Berville and the sea would have the effect of deepening the channel to 26 feet below zero of the lowest low-tide, by increasing the mean velocity of the current between the walls to 2 knots an hour; but Mr. Lavoinne not only considered it would be impossible to maintain so great a depth, but that the attempt to do so might completely destroy the regimen of the estuary. He was of opinion, moreover, that it would be sufficient for the needs of the navigation if trading vessels were able to ascend to Rouen under the same conditions as at other tidal-ports; in short, that a depth of about 25 feet at high-water of neap-tides, which would only require the lowering of the bed to $4\frac{1}{2}$ feet below zero, would be an ample depth to maintain throughout the channel. With this object in view, he proposed such a width of channel as would ensure a mean velocity of $1\frac{1}{2}$ knot an hour between Tancarville and the meridian of Havre. Sir Charles Hartley would not presume to criticise the project of the late Mr. Lavoinne, who made, it might be said, the improvement of the Seine the study of a lifetime, but he regretted that the late Engineer-in-Chief of the tidal Seine did not consider himself justified in recommending the establishment of a much greater depth than $4\frac{1}{2}$ feet below extreme low-water between the training-walls. For his own part, he considered that a depth of at least 12 feet below zero should be aimed at, a disposition which would involve the establishment of a somewhat narrower channel, and an extension of the pier-heads into deep water; but in his opinion the expense of the additional prolongation of insubmergible walls would be far more than compensated by the greater probability of success, both in an engineering and a commercial point of view, which would attend the operation. Apart from this provision to secure a greater depth, he considered the alignment of the walls to be judiciously planned for securing a stable channel, and for this purpose he could suggest nothing better than the continuously concave southern wall from Berville to the sea. This wall, by completely closing the Villerville channel, which now brought in from the south the greater part of the alluvion deposited in the outer estuary, would moreover ensure the maintenance of a single channel directed towards the north-west in the natural direction taken by the ebb-tide. Again, the entrance was at a spot where erosion was more marked than elsewhere, and where the "Thalweg" was as deep as at any former period. These great advantages would, in his opinion, be lost if the Author's proposed bell-mouth plan below Honfleur were adopted, and he thought therefore that the special but minor advantages, claimed by the

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Author (but which, however, were not admitted by Mr. Lavoinne) in support of his own plan, were no equivalent for its far greater inherent disadvantages as an agent to secure a permanent deep-water entrance to the Seine. Although Mr. Lavoinne advanced many arguments to show that the prolongation of the training-walls would effectually ward off all danger of injurious silting up in the sea approaches to Havre, it was not pretended that otherwise the extension of the embankments would be of any benefit to that port. It was indeed predicted by not a few engineers and mariners, that the completion of the estuary-works would gravely imperil the conservation of the position it now enjoyed of being the second port in France. Nor was it surprising that such fears were entertained, when it was remembered that the draught of vessels trading to Havre was already limited by the depth of water over a wide zone in front of the port, on which there was a depth of only $26\frac{1}{2}$ feet at high-water of neap-tides; the range of tide being 24 feet at springs and 12 feet at neaps, and the depth at the entrance to the harbour being only maintained at $8\frac{1}{2}$ feet below low-water of spring-tides by constant dredging. On the other hand, the fixity of the bed of the sea in the immediate neighbourhood of Havre should beget confidence; for, comparing together all the surveys which had been hitherto made, the unchangeableness of the bed of the roadstead was proved beyond a doubt. This happy circumstance was due, according to Mr. Lavoinne, to the complete absence of matter held in suspension by the alternating tidal currents, and to the independence which existed between the travel of the shingle coming from the north, and that of sand and silt from the south. To this exceptionally favourable condition of things he attributed the immutability of the deep-sea approach to Havre, and he appeared to have had good reasons for concluding that works, such as he proposed for the improvement of the estuary, would not be prejudicial to Havre so long as the double action of the tides and littoral currents continued to prevail. If, however, contrary to Mr. Lavoinne's expectations, further investigations should give good grounds for apprehending the consequences of prolonging the training-walls across the bar into deep water, it would then be more prudent "to let well alone," and to adopt the safest solution of the difficulty, namely, that of digging a deep lateral ship-canal instead of a barge-canal between Havre and Tancarville, and of restricting the extension of the embankment-works to a judicious *raccordement* of the existing walls with the shores of the estuary in the direction of Honfleur.

Three projects among many others for the improvement of the port of Havre were now being warmly discussed in France—
 1st, the project of a large body of experienced naval officers, for the improvement of the existing port by the construction of a breakwater to protect the small roadstead and the existing entrance; 2nd, the project of the Government engineers to suppress the existing entrance (which was directed south-west), and to substitute a new one turned towards the north-west, and the creation of a tenth basin by encroaching on the sea. The expense of these works was estimated at £3,200,000; 3rdly, the project of Mr. Hersent, which embraced three distinct improvements—*a*. The protection of the small roadstead and the existing entrance by a series of isolated breakwaters, beginning at Cap de la Hève, and extending over a length of $4\frac{1}{2}$ miles (including the width of the six openings between the breakwaters) at an average distance of 1 mile from the shore to a point due north of the Ratier bank; *b*. A continuation up-stream of the line of breakwaters by the construction of an insubmergible training-wall to a point 1,600 feet immediately opposite Berville, and of a south training-wall from the latter to Honfleur, where the width of the channel would be increased to 5,000 feet; *c*. The construction of an insubmergible wall round the Ratier bank, in order to ensure the deepening of the two channels, by fixing the position of the north and south currents which separated the channels at the present time. The total estimate for this comprehensive project was £6,706,000, but it was anticipated that of this sum £4,236,000 would be obtained by the sale of reclaimed land behind the training-walls, thus reducing the total sum to £2,470,000. These projects differed so greatly from each other that no better instance could be given of the diversity of opinion that existed in France as to the best means of improving the port of Havre. Moreover, this important question could never be separated from that of improving the estuary of the Seine, when the latter subject was under discussion, and therefore the port of Havre had been somewhat prominently referred to in his remarks on the Author's valuable Paper on the River Seine.

Captain GRAHAM H. HILLS observed that the Author had made valuable additions to the facts which in previous Papers he had contributed to the records of the Institution. But in Chapter III. on estuary works he quitted facts to enter the region of speculation, and committed himself to a scheme suggested by the late Mr. Lavoinne, formerly District Engineer for the tidal Seine, stationed at Rouen. The Author stated his objections to some

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Captain Hills. details of Mr. Lavoinne's scheme, but accepted his main argument in favour of a seaward extension of the existing walls, and produced a design showing the modifications of Lavoinne's plan which he would approve. The arguments as put forward by both writers involved important admissions, which might be thus summed up:—

1. The deposits which had formed accretions in the Seine were derived from erosions from neighbouring sea-coasts borne by ocean-currents ranging along those coasts, until traversing the opening of the Seine estuary they were deflected, and their suspended matter was deposited where shelter from prevailing winds was provided by the features of the estuary.

2. Since the commencement of the training-walls in the Seine in 1847 down to 1880, the bulk of the deposits outside of the channel between the training-walls was estimated at 312,000,000 cubic yards; and it was stated by Mr. Lavoinne that eventually the whole spaces now proposed to be cut off from the estuary by the extended training-walls would be filled by similar deposits.

3. It was also admitted that between 1875 and 1880 a large accretion had occurred in the seaward parts of the estuary between the coasts of Havre and Villerville.

On these points he would observe:—

1. As the training-walls were advanced seaward, the conditions of shelter tending to promote deposit were favoured, and as accretions grew the favourable conditions of increased shelter grew also.

2. That the loss of capacity in the tidal-estuary implied by the accretions already recorded, together with that of all future accretions, implied a diminished energy of tidal-stream in the sea-channels, and consequent enfeeblement of the power which tended hitherto to their maintenance.

3. The contention that alternations in the depths of the sea-channels existed before the training-works were commenced, and that losses of capacity similar to those which occurred from 1875 to 1880 used to occur and were subsequently righted by natural causes, was irrelevant, in face of the great changes made in the natural features of the estuary, changes which had altered the effect and operation of natural causes. Assuming, but not granting, that deposits in the sea-channels might have been due mainly to peculiar seasons of storm, the tidal-action being impaired in its out-flow by the tidal abstraction already accomplished, the process which formerly operated to clear out such deposits was proportionately enfeebled; it was therefore mere assumption to maintain that the future could develop such alternations as were said to have occurred in the past. The extension of the training-walls as now

proposed would leave the estuary-channels to continue hereafter Captain Hills. their vagrant tendencies within the limits restricted by the walls; within those limits the elevation of the banks would be promoted by the enfeeblement of the powers which had hitherto resisted or counterbalanced the on-shore drift of storms, and eventually, if the importance of the commerce of the country through Rouen seemed to require it, new training-walls would be established forming a narrow channel sufficient to drain off, and to be maintained by, the tidal and upland water of the river Seine, ending on the sea margin of a delta, such margin falling in with the sweep of the coast-line and the ocean-stream which ranged along it.

Mr. J. HORAN held that it could hardly be said that the advance Mr. Horan. made in the science of the treatment of estuaries, with a view to their improvement for navigation, had kept pace with like progress in other departments of modern engineering. Whether this had arisen from the complication of the subject, or that its masters had relied upon individual judgment, followed by tentative work in the few cases successfully treated, without forming or formulating any clear views towards generalization, certain it was that the little knowledge obtainable was to be had only from applying the abstract views of writers on the theory of tides and waves. From the idea of a succession of equal waves in open water, it was only a step to form a conception of the succession of diminishing waves which followed the entry of a tidal-wave into an estuary; diminishing, first, because of the opposition encountered from friction in the channel and other obstacles, and, secondly, from the opposition offered by the descending upland water, and in some cases by a reflected tidal-wave. The diminution effected in this way was not necessarily in all the dimensions of a wave, but related rather to the energy transmitted by a wave to its successor, reckoning from the sea upwards. The phenomena were masked by the great length of the waves as compared with their height, and by interference of the descending upland water when its volume became comparable with the volume of sea-water entering, or with the volume of any of the subsequent transmitted waves. This interference went so far sometimes as to give rise to a bore, just as the mutual opposition of waves produced a chopping sea, or as breakers were formed on a shelving shore, for it must be kept in mind that the oscillation, or to-and-fro movement, produced by a passing wave had its speed lessened on the flow, and increased on the ebb by the descending river. From a consideration of the subject in this light, it followed that there must exist in every tidal estuary, not possessing conditions which

Mr. HORAN. might be inferred later on, a state of affairs analogous to what was known as the head of a tide, namely, a region mostly well marked by deposition and an unsettled state of the currents; but owing to the varying relative quantities of tidal and upland waters, this area was not in all cases easily defined. Works undertaken solely for the improvement of the river above this area would tend ultimately to close the estuary, because if such works, by unduly narrowing the channel, increased the velocity of the upland water, the area of deposition would be prolonged towards the estuary mouth, opposition would be offered to the progress of the tidal-wave sooner after its entrance, and the quantity of slack water in the estuary at every tide would be increased as compared with the volume of the sea-water entering. These effects would take place even when the flow of upland water in a given time bore a small ratio to the incoming tidal water in the same time, for scouring power increased rapidly with increase of velocity. A good river could be formed by treatment of this nature at the cost of destruction of tidal-action in its estuary, but clearly the mouth of such a river would always be a problem requiring solution. On the other hand, works to facilitate the passage of the incoming tidal-wave would have the effect of extending the area of deposition up the river, and would also give due scope to the scouring action of the upland water when the tide was on the ebb. Deposition would in this way become distributed over the entire tidal-channel, and in case of upland floods of magnitude, large quantities of silt might be cleared quite out of the estuary and be deposited at sea. This was the maximum result attainable, and hence the soundness of the most successful practice, namely, extending low-water line as far as possible up the river. So viewed, the vexed question of the relative values of tidal and upland waters as scouring agents became narrowed to a question of relative volumes and velocities. The existing works on the Seine could only benefit Rouen at the expense of the ports lower down, and were a warning of the general necessity for united action on behalf of all the interests affected, as against partial treatment of such an estuary. A scheme to preserve a good entry to Havre and Honfleur should include a modification of the channel above Berville, probably to increase its cross-section by dredging, as being the only means now available, since so much of the tidal room had been already lost by the great accumulations at this part of the river.

Mr. LAW. Mr. HENRY LAW considered the first division of the Paper as of peculiar interest. The subject of hydrology had received far less attention in Great Britain than it deserved, and unfortunately the systematic study of the hydrology of the river-basins was

rendered impossible by the irrational manner in which the Mr. Law's districts for water-supply, drainage, and river conservancy, were determined. Obviously these districts should be determined by the physical features of the country, and the boundaries should be coterminous with those of the basins, or water-sheds. But as a matter of fact they were determined by the fanciful boundaries of parishes, with the most supreme disregard of the situation of rivers, valleys, and hills. The object of conservancy boards was limited to the preservation and improvement of navigation, their powers were confined to the river alone, and frequently to but a very limited portion of that. If there were a controlling board of conservancy for each large river-basin, then systematic observations could be taken as to all the physical characteristics of each basin, the extent of the several subsidiary valleys, and the distances upon the main stream at which the tributaries from such valleys joined it, gaugings of the various streams under varying conditions, the amount and distribution of the rainfall, the proportions of rain evaporated, absorbed, and delivered from the surface, depending upon the geological characteristics of the soil and of the strata beneath, and the inclination of the surface, and whether bare, cultivated, or covered with wood. One most important matter which influenced the volume of the flow of rivers at different parts of their course was the absorptive or otherwise nature of their bed; and whether the level of the surface of the river was higher or lower than that of the water contained in the surrounding strata. In some cases it would be found that a portion of the water of the river was absorbed by the bed, and passed into the surrounding strata, of which instances occurred in the Chelt, the Mole, the Stour near Canterbury, and streams at Mimms in Hertfordshire, which latter had no outfall whatever, but were entirely absorbed by the Chalk. In other, and those the most frequent, cases, the river as it pursued its course was fed by springs in its bed, which might be from the superficial strata, or from deeper-seated beds; as an instance, the Thames derived nearly half its flow from spring-water entering through its bed. Observations showed that the water in the Chalk on each side of the valley of the Thames stood at a height of several hundred feet above the river, and as the river was approached, gradually fell until it attained the same level: and much interesting information on this subject would be found in the discussion upon a Paper by the late Mr. P. W. Barlow, M. Inst. C.E.¹

¹ Minutes of Proceedings Inst. C.E. vol. xiv. p. 42.

Mr. Law. It would be difficult to over-estimate the advantages which would result if each large river-basin had its conservancy board with the requisite control over both the land and the water within its district, and which had rating powers by which the means could be provided for making the necessary surveys, conducting the necessary observations, and adopting measures for preventing or mitigating floods, and for improving both the drainage and the navigation. The Author showed how much had been done in the case of the Seine to mitigate floods, by the construction of movable weirs, and by the transmission of warnings to the weir-keepers whenever the upper reaches of the river were in flood. Nothing could be simpler than an automatic apparatus to transmit and record electrically the rise and fall of the river at any point desired, however distant that point might be.

The second division of the Paper was most important, and the details there given as supplemental to the Author's former Paper were of great practical utility. There could be no doubt that the rapid and general development of the railway system in this country had led to the inland navigation being much neglected, and that as a consequence the same attention had not been paid as in other countries, to the improvement of weirs, by means of which while a sufficient depth of water might be retained in dry weather for the purposes of navigation, the rapid discharge of large quantities of water in times of heavy rainfall should be provided for, so as to avoid flooding the adjacent country.

The lessons to be learned from the works, described in the third division of the Paper, which had been executed in the estuary of the Seine, were not only of great importance from the magnitude of those works, from the striking character of the results (so different from those anticipated by the projector), and the rapidity with which those results had been realized; but the subject had special interest from the use made of the experience gained in the treatment of the Seine by the engineers engaged in the great parliamentary fights over the proposed Manchester Ship-Canal.

The arguments, which the opponents to the schemes for the Manchester Ship-Canal founded upon the experience derived from the Seine, might be thus briefly stated: From the peculiar contour of the coast at the mouth of the Mersey, the sea was always endeavouring to close up the entrance to the river, and to form a continuous beach extending from the Lancashire to the Cheshire shores. Were it not for the tidal-flow twice every day of the water entering and leaving the mouth of the Mersey, that mouth would be entirely closed; but the constant passage of this water

forced an opening for its escape, the dimensions of which passage Mr. Law. were dependent upon the quantity having to pass. There were here two antagonistic forces in play, namely, the sea constantly endeavouring to close the mouth, and the passing water as constantly endeavouring to force a passage; and these forces were so nearly balanced that sometimes the one, sometimes the other, predominated; the depth of water and the position of the bar altering from time to time, according as the volume of tidal water, or the force and direction of the prevailing winds varied. It had been proposed in the first two schemes to construct training-walls, to form a definite channel through the sandy inner estuary of the Mersey extending from Garston to Runcorn. The opponents of these schemes appealed to the experience gained from what had occurred upon the Seine (amongst other rivers) in support of their contention that wherever training-walls, were they high or low, were made to form a comparatively narrow channel through a wide sandy estuary, the waters of which were loaded with solid matter in suspension, accretion behind such walls was inevitable. And they went on to say that the effect of such accretion in the Mersey would be to diminish the tidal-capacity of the inner estuary, and as a consequence to lessen the quantity and force of the water entering and leaving over the bar; thus giving a preponderance to the efforts of the sea to increase the height of the bar, until the diminished area of the channel over the same had become adjusted to the diminished flow of water. It was also contended, with apparent reason, that these effects would be cumulative; that, as the banks increased in height, it would become necessary to raise the training-walls, which would again cause a further increase in the banks, until the whole of the inner estuary had been raised to the level of high-water. It must not be supposed, however, that those who adopted this line of argument condemned the use of training-walls. In many situations they were of the greatest value, amongst others where it was desired to canalize a river, and where there was either no bar, or where the training-walls could be carried beyond the bar into deep water.

In Mr. Law's experience, increased depth of channel when produced with due regard to the general regime of the river was always attended by increased tidal capacity.

Mr. L. PARTIOT, having been for nine years in charge of the Mr. Partiot. embankments of the tidal Seine, had had opportunities of carefully studying the question. He had presented various schemes which up to the present time had never been seriously examined; per-

Mr. Partiot. haps because they comprised in one project the improvement of the Estuary of the Seine as a whole, entailing a large outlay ; perhaps because of the antagonism between the ports of Havre and Rouen, which preferred plans exclusively favouring their several interests. The question having recently been reopened by the French Government, he had taken the opportunity of setting forth his views in a memoir.¹ He had approached the subject from a new side, namely, that of the effects produced by the "narrows," which often separated the estuary of a river from the open sea. It appeared to him quite possible from this point of view to assure a good outfall, while satisfying at once the interests of Havre, of Honfleur, and of Rouen.

He had noticed that when the estuary of a tidal-river, of which the bottom was sandy, was separated from the open sea by a narrow strait, there was produced in the latter a great depth of water, which did not shoal immediately above or below the narrows, but formed channels extending to a considerable distance on either side. He cited in his memoir the outfalls of the Gironde, of the Scheldt, of the Tagus, and of the Mersey, and added that these interior estuaries, which formed in advance of the actual outfalls, remained unchanged for centuries, without being silted up either by the river or by the sea. This rule was equally applicable to bays, such as those of Arcachon and Poole, which only received very small streams. He thus explained this law : When a mass of water, which entered into and retired from a bay passed through a very narrow entrance-channel in a soft bottom, the velocity of the current was augmented, and equilibrium between the bottom-velocity and the resistance of the bed could only be established by a deepening of the latter, varying in extent with the amount of discharge and the width of the channel. The sand in the estuary above was brought down by the ebb through the trench thus produced, and there were formed, by the propagation of this movement, one or several channels, of which the dimensions were dependent on the amount and the duration of the ebb-tide. An analogous cause acted to form, by the flood-tide, a similar channel below the estuary. The sands, thus definitively displaced by the formation of the channels, were deposited in banks above or below the estuary-mouth. In the long extent comprised between the origin of the estuary-channel and its disappearance seaward, the currents did not allow stones, sand, or silt to become stationary.

¹ "Projet des Travaux à faire à l'Embouchure de la Seine. Par L. Partiot, Inspecteur Général des Ponts et Chaussées." 4to. Atlas of Plates. Paris 1886.

They moved up and down, and when the river was of such extent Mr. Partiot. as materially to add by its discharge to the volume of the ebb, they were finally carried out to sea. Mr. Partiot thought that if a channel or gullet, such as that of the Pointe de Grâce, at the outfall of the Seine, were made artificially, there would be produced in the gullet great depths, which would be developed into deep channels, over long distances above and below the new pass. Above there would be formed, between Honfleur and Havre, an extended anchorage. The Author proposed to achieve this result by constructing a mole to above high-water mark, between the Amfard Bank and Villerville, a point situated between Trouville and Honfleur. Only a channel of 6,560 feet wide would be left in front of Havre. Nature appeared to have accomplished by herself a similar operation at the outfall of the River Foyle. The works would be completed by training the Seine between an extension of the embankments as far as Honfleur. This plan would admit of the largest vessels entering Havre at any time; of entering Honfleur at every high-tide; and would allow, even at neaps, of vessels of 800 tons ascending as far as Rouen.

Mr. A. DE PRÉAUDEAU remarked that the hydraulic apparatus at Mr. de the Bougival lock presented the peculiarity that it was actuated Préauveau. by the lowering of the neighbouring weir. This weir had a sill sufficiently high to assure a permanent drop, and situated, on the left bank, there were hydraulic engines, which served to supply Versailles with water. On the right bank there had been installed, within the body of the weir, two turbines, which worked the pressure-pumps. With the ordinary fall of $6\frac{1}{2}$ to 10 feet, a single turbine sufficed for all the work; but when the fall was reduced by floods to about $2\frac{1}{2}$ feet, the use of both turbines at once might be necessary. The turbines might also be used, should the navigation require it, as sources of power for providing electric-light to the locks.

Between St. Aubin and the mouth, the level of the Seine was constantly affected by tidal oscillation, and important modifications in the behaviour of its waters had been observed since the construction of the embankments. At page 245 of the Paper, it was stated that, "The range of spring-tides, which amounts to 23 feet 7 inches at the mouth of the Seine, is reduced to about 10 feet at La Mailleraye, and to 6 feet 7 inches at Rouen;" in 1861, this amplitude was only 4 feet 7 inches at Rouen. At neap-tides, while there was a depth of 11 feet 5 inches at the mouth, the depth at Rouen had been increased from 2 feet 3 inches in 1861, to 3 feet 7 inches in 1875. In other particulars, the regimen of the river had undergone

Mr. de
Préaudeau.

changes as notable. For navigation, the most favourably situated estuaries were those in which the level of high-water increased regularly and continuously from the mouth to the limit of tidal-action. An example was offered by the river Gironde, which showed that this condition corresponded to great depths near the sea, and to a relatively high rate of discharge of the river. It was not so in respect of the Seine, where the level of high-water springs was, at Quillebeuf, 1 foot 9 inches higher, falling at Duclair to $5\frac{1}{2}$ inches lower, and rising again at Rouen to 8 inches higher than at Havre. Before the embankments were made, high-water rose to about the same level at Rouen as at Havre. The height was less at Quillebeuf, and the depression at Duclair was more sensible. The works having facilitated the action of the tides and of the currents between the embankments, the level of low-water at lowest tides had been decreased between 1840 and 1875 by 2 feet 6 inches at Honfleur, by 4 feet 10 inches at Quillebeuf, by 3 feet $8\frac{1}{2}$ inches at Duclair, and by 4 feet 3 inches at Rouen. From that, it resulted that the difference of low-water levels had varied little between Rouen and Villequier (44 miles), while it had diminished between Villequier and Havre (32 miles). The level of high-water neaps was slightly lowered, it only rose 10 inches higher at Rouen than at Havre, instead of 1 foot 9 inches. It was known that in estuaries as on the seashore, the tides fell lower at springs than at neaps. This did not occur in the tidal part of rivers, when the volume of water sent up by the high-water of spring-tide had not time to pass off so completely between two tides as was the case with neaps. Therefore, the point below which the level of low-water spring-tide was higher than that of neap-tides, defined the limit of the estuary and the beginning of the river. Now this point had changed in the Seine by reason of the works; in 1861 it was 14 miles above Havre; in 1866, 22 miles above, and in 1875, 46 miles above, or midway between Villequier and Quillebeuf.

The essential difference between the profiles proposed by the Author (Plate 4, Fig. 8), and Mr. Lavoinne (Plate 4, Fig. 9), consisted in that the Author left a channel between the Ratier bank and the south shore, which channel Mr. Lavoinne proposed to suppress. Without discussing the details of the lines to be followed between Tancarville and Honfleur, Mr. de Préaudeau thought he was able, from totally different considerations, to support the Author's views. The flood-tides which contributed to the volume of the maritime Seine, appeared to be derived from two principal directions, an ocean-current traversing the Channel from Cape

Barfleur to Cape Antifer, and a littoral-current which reached the mouth after having traversed the whole of the Calvados coast west and south of the estuary. The ocean-current first reached Havre and the estuary, it afterwards united with the littoral-current, which was thus conducted at an increased velocity to Honfleur. The mingling of these two currents of unequal velocity, and the decrease of the northern current, produced, an hour and a half before high water, a deviation of the flood-tide before Havre, which took a north-north-westerly direction, hugging the shore. The velocity of these currents bearing seaward augmented rapidly, and attained its maximum shortly after high-water at Havre. Now the embankment of the Seine had produced in the estuary a twofold result—diminution of capacity above the mean level by reason of silting, and lowering of the beds in the channels. From the former cause filling took place more quickly than formerly; from the second cause the ocean-current, which arrived first, contributed the more largely to filling. These conditions did not favour access to the port of Havre, and their aggravation should be avoided. It, therefore, appeared that the profile of the embankments should be so disposed as not to facilitate the introduction of the ocean-current, and not to hinder the introduction of the littoral current coming from the south. At present three channels served for the introduction of the tide; they were separated by the Amfard and Ratier banks. Both the schemes under consideration suppressed the channel north of the Amfard, and were so far equivalent; but it could not be doubted that the closing of the channel south of the Ratier would be prejudicial to the introduction of the littoral current. Mr. de Préaudeau, therefore, concurred with the Author, that this channel should be kept open. He would add that, in his opinion, the part of the embankments projected below Honfleur would not be of immediate utility, nor perhaps, even of future advantage. The displacements of the channel had always originated a short distance from the extremities of the embankments at about 6 miles to the east of Honfleur. If the channel were fixed by a prolongation of the embankments, and conveniently widened as far as the meridian of Honfleur, it appeared possible that the combined action of the waves and of the ebb-tide would be sufficient to maintain west of Honfleur the depth necessary for navigation. Therefore, the embankments should be first prolonged as far as Honfleur, and not beyond that point until after the results of sufficient experience had been ascertained.

Mr. de
Préaudeau.

Mr. H. S. RIDINGS thought that greater prominence should be Mr. Ridings.

Mr. Ridings. given to cheap (and at the same time effective) methods of controlling rivers which were sometimes applicable. Expensive stone training-walls were in many cases out of the question in poor countries, or where the improvements had to be carried out by small companies or boards of conservators. Also in alluvial districts it often happened that stone could not be obtained, except from a great distance and at heavy cost. His experience in connection with the improvements of the Digue entrance of the Magdalena river, in the United States of Colombia, pointed to the fact that rough logs of timber used as piles (driven as a rule very easily) formed an excellent substitute for stone training-walls. The piles need not be driven close together. There was a sensible diminution of the current behind the piles, and as a consequence a deposition of silt. When the deposit had risen to a certain height, means should be taken to protect the edge next the navigable channel in certain parts, either by close piling, by pitching, or by "mattresses."

As was well known, in many tropical countries, rivers which in the wet season were torrential, in the dry season became small streams. Where land was not valuable embankments might be thrown across valleys, or advantage might be taken of natural depressions, to turn a part of the flood-water into them, thus forming lakes, which in the dry season would become feeders to the main channel. Though this might not be of much service for purposes of inland navigation, it would be of immense service for irrigation. If such a system as this could, for instance, be carried out in connection with the Orange River in South Africa, the advantages would be incalculable.

Mr. Siccama. Mr. H. T. H. SICCAMA remarked that the estuary of the Seine resembled the river Mersey in that it was a river falling into a sea-bay. The true river mouth was at Quillebeuf, up to which point, till the middle of last century, the sea reached. The land reclamation to the west of Quillebeuf dated from 1758, when the Digue Blanche was laid, cutting off the still existing lagoon and surrounding land from the sea. As the volume of water flowing in or out of the river itself could not have sufficient power of scour on the bar, land reclamations in the bay might be a cause of the shallowing between Havre and Honfleur. To cut off more submergible surface would only tend to form a delta lower down, with shifting channels, in a more exposed situation.

Another great point for consideration in estuary-works was the direction in which the tidal-wave approached the coast, as the deepest passes across a bar lay, as a rule, in what might be

called "scooping on the tide." This might be seen by a glance at Mr. Siccama. the North Sea chart of the Dutch coast for instance. Here the tidal-wave, coming up from the Channel with an average current of 3 miles an hour, approached the estuaries of the Scheldt, the Maas, and the Rhine, and the narrows of Texel and Vlieland, in a direction from the south-west to the north-east, and all the deepest passes across the bars opened up against the south-west.

The great scouring agent in these passes was the current of the rising tide, the velocity of which was not due only to gravity or to the head between high- and low-water, as the current continued to flow for a time at any place after the top of the tidal-wave had passed that place. Nothing should be done tending to check this current by suddenly narrowing the bed or deflecting the direction, as in this case the living force was broken, and only the current due to head was left. The ploughing up of the channels was done by the rising tide, and the sand or silt thus lifted was carried out to sea by the ebb-tide. The unsatisfactory results of the works at the new waterway at the mouth of the Maas was due to losing sight of this fact in devising the intended improvement. This entrance opened at right angles, or nearly so, to the direction of the littoral current, which, therefore, instead of rushing up the estuary in nearly its original direction, swept by, while only a portion of the tidal-wave entered the river mouth. The position of the jetties at the mouth, too, caused great disturbance in the current, which formed continually-shifting pools and tortuous channels, which would not have occurred had their heads been parallel or tangential to its direction. In the Seine, the influence of the littoral current would probably be less than in the case just mentioned, as Havre and Honfleur were situated in a bay; but the tidal-wave coming round Point Barfleur would set up a current which must be of importance for scouring purposes.

Mr. F. G. M. STONEY had devoted much time and attention to Mr. Stoney. weirs and sluices¹ during the last seventeen years, and his experience had confirmed him in the belief that no form of fixed obstruction or uncontrollable weir should be allowed in a river. Whatever form of movable weir was used, it should not shut into the water, nor down on the bed of the river, when open. Above all things, the full capacity of the river should be preserved when the weir or sluices were open, and the sills should be at the bottom of the river, and all should open upwards from the

¹ Minutes of Proceedings Inst. C.E. vol. ix. p. 85, and Plate 6.

Mr. Stoney. bottom. As an illustration of these principles, Mr. Stoney had erected, some three years ago, a removable weir consisting of four sluices at Belleek, in Ireland. The object was to prevent the flooding of the Erne lakes, which were about 50 miles long of unbroken water, and in which the winter floods rose 9 feet above summer-level. Had the river outlet from the lakes been simply enlarged and deepened, the existing navigation and mill-powers would have been destroyed; but the large sluices were put up to retain water to almost old summer-level, and of such depth and magnitude as to ensure efficient control of any possible flood. These sluices were simply large wrought-iron doors, which shut down tight against planed iron sills set in the bed of the river, and they were lifted vertically from the bottom clear out of and above the running stream at maximum flood.

The great water-pressure against the gates was so transferred to free rollers, that a pressure of 90 tons on each gate was not perceptible, and one man could at any time work the sluices by hand-power. Each gate was 31 feet 6 inches span from centre to centre of the free rollers, 29 feet 2 inches clear span of opening, and 14 feet 6 inches deep. Mr. James Price, Jun., the Resident Engineer of the works, had recently informed him of the working and effect of these sluices after having discharged three winters' floods. Mr. Price had allowed 15 feet 6 inches head of water on the gates, that was 1 foot over the top; but could not feel any difference in pressure on the hand-power over the force required to lift the gates out of the water. The sluices had adjusted themselves perfectly watertight; they never required any repairs. Nor had the least trouble from débris or floating bodies obstructing the rollers been experienced, although there had been a continuous flow up to 700,000 cubic feet per minute through the sluices, often bearing down timber and dirt after the bursting of dams in the works above; everything was carried naturally past, clear of the roller recesses. The whole arrangement of sluices had given complete satisfaction, and the effect in controlling the drainage was all that could be desired. Mr. Stoney added that the additional experience gained from these sluices had more than confirmed all previous expectations as to the working of free rollers on vertical planes, and he saw no practical limit to their advantageous use in very large spans. It was not a question of expediency as to other circumstances and local fitness. As to cost, a movable dam made on this principle would favourably compete with any other structure of like span and depth, while it would be more reliable and efficient. Sluices of this kind

could also be made to allow a large ship to pass through the sluice- Mr. Stoney. openings in a short space of time.

Mr. L. B. WELLS observed that the information given in the Mr. Wells. Paper on the hydrology of the basin of the Seine naturally directed attention to the principles which obtained in all river basins. In Cheshire the floods in the River Dane, with sources on the steep hillsides of West Derbyshire and Staffordshire, partook somewhat of a torrential character, while in droughts the river dwindled to very small dimensions; whereas the Weaver, rising in the pervious strata of the low sandstone hills of Cheshire, and having less fall to the sea, was more equable in its flow, and maintained a good supply of water for navigation purposes even during such dry summers as those of 1884 and 1885. The advantage of a system of communication by telegraph, giving warning of heavy rainfall in the district, established upwards of twenty years ago by Mr. E. Leader Williams, when engineer for the Weaver, and of late supplemented by telephonic communication at each weir, had been fully proved. This enabled the sluices to be worked in advance of floods, and the river to be regulated so as to interfere with navigation as little as possible, and yet provide for the passage of the flood-water. It would be interesting to know in what way the floods on the Seine had been influenced by the navigation-works, which must of necessity include the removal of shoals, if not of bends in the river, as well as the construction of locks and weirs. The results might further help to throw additional light upon the old controversy which arose when the Bills for making the Severn navigable were before Parliament, which were revived when the Author's Paper on "Fixed and Movable Weirs" was considered by the Institution in 1880. At that time Mr. Wells mentioned works lately finished and in progress on the Weaver, to provide increased depth for navigable purposes, and to facilitate the passage of floods. Two fixed weirs, by which the water was ponded, were being removed, and eight sluices being erected across the river at Dutton, of 15-foot span, 13 feet deep, with a rise of 9 feet 3 inches at the sluices. Under ordinary circumstances the water flowed over the tops as at the stone weirs, but in floods, by raising the sluices, the river was allowed an uninterrupted flow, and as the sluices were worked from an overhead bridge, there was no danger to attendants, and the necessary work of lifting and lowering could be done effectively, and the river regulated provided the channel below was of sufficient capacity to carry off the flood-water. Following this and minor improvements in the same direction, all tending to the benefit of the navigation, the floods in the

Mr. Wells. Weaver had been brought under better control, and the flood-level lowered, while no interruption to the navigation had occurred through any failure of the sluices. He noticed that the Engineer for the proposed Manchester Ship-Canal, in his Parliamentary plans, had adopted a similar description of weir for maintaining and regulating the waters of the Mersey for navigation purposes. The Author had in 1880 questioned Mr. Wells' view of the trustworthiness of the French movable weirs; but seeing that French engineers were still altering their type, he felt certain there must be some good cause for dissatisfaction. The reports in 1873 by Messrs. W. Forsyth and W. R. Manning, M. Inst. C.E., to the Board of Public Works in Ireland, dealt with the needle-weir, the water-pressure weir, the pontoon-barrage, the drum-weir, and the shutter-weir, each of the systems being in use. The Author stated that shutters had given place to needles and needles to curtains, while now the need was acknowledged of a fixed overhead bridge for working the weir, to which the frames were hinged, not at the bottom of the river, as in the older weirs. The latter type commended itself to him; still the grave objection of a multiplicity of parts remained; these he thought would be liable to derangement, to damage by floating bodies, and to become unworkable during frost. In some ponds on the Weaver, the limit to which the water could be raised had been almost reached, and vessels availed themselves of every additional inch of depth; the water-level had therefore to be closely adjusted, and he had not found any self-acting caps satisfactory. He had tried the cap described by Mr. Baldwin Latham in 1880, and which he had seen working at Nantwich;¹ but there must be a variation of 18 inches in the level of the water to allow a cap 13 inches deep to work, and this exceeded the limit permitted. He had also tried butterfly-valves somewhat similar to those shown in Plate 3, Fig. 8; but found they were not self-acting, and were very liable to foul. He was glad that increased attention was being given to inland water-ways, which, although little considered in this country for half a century, would, he ventured to predict, reassert their worth, and when sufficiently developed prove a great boon to commerce. At present it was next to impossible to obtain goods by canals. They must be freed from railway control, and through routes opened and canals enlarged to a sufficient capacity. It would then be found that for certain classes of traffic they afforded the best means of

¹ Minutes of Proceedings Inst. C.E. vol. lx. p. 95.

transport. No less than 1,000,000 tons of salt were taken to Mr. Wells. Liverpool annually by the Weaver, and not a single ton was conveyed by rail. Water-carriage competed successfully with railways for the conveyance of salt to the Tyne, although the cargo had to be trans-shipped from a Weaver barge into a sea-going vessel, and then made the circuit of England, a voyage from point to point of 1,000 miles, whereas the distance by railway was only 170 miles. After the Upper Seine had been deepened from $5\frac{1}{4}$ to $6\frac{1}{2}$ feet, the traffic was stated to have grown 100 per cent., whilst the outlay was not raised more than 50 per cent., and this in France, where the population was not increasing as in this country. He should like to hear the reason for fixing 10 feet 6 inches as the depth of the Lower Seine navigation. He understood the standard canal-depth to be 6 feet 6 inches, as adopted on the Eastern Canal of France and on the Upper Seine. A depth of 10 feet 6 inches was needless in the Lower Seine for vessels trading further inland, but not deep enough to accommodate the ordinary coaster. Coasting steam-vessels were rapidly taking the place of sailing-vessels; these required from 11 to 13 feet depth of water. The Lower Seine could therefore only be used by a class of craft whose voyage must be within the limits of Paris and Rouen, or at the utmost between Paris and Havre.

Mr. W. H. WHEELER considered that the system of flood-warn- Mr. Wheeler.
ings described by the Author as carried out on the branches of the Seine might usefully be followed in this country, especially on those rivers which passed through low, flat districts. He had frequently brought this matter before the authorities having control over the Fen rivers, but no steps had been taken to put such a plan in practice. He did not gather from the Paper that the training-works in the upper estuary of the Seine had so far caused any detriment to the port of Havre, nor could he see any cause for alarm that such should be the case. On the contrary, it seemed that the channel from the end of the trained-work to the sea had rather improved than deteriorated since the work had been done, the difficulty of navigating this portion of the estuary not arising from the depth of water but from the shifting character of the channel, a defect that had always existed. True, the tidal capacity of the estuary had diminished since the training, but to what extent this was due to the training-works was difficult to determine, as it appeared from Mr. Lavoinne's observations that the capacity of the estuary thirty-two years ago at the lower part was even less than it was now. From the fact that the estuary had deepened below Havre, it would seem as if a portion

Mr. Wheeler. of the sand which had oscillated between the upper and lower part of the estuary had now become fixed in the upper part, and the estuary to this extent permanently improved. In this, as in all other similar estuaries, there was a large mass of sand lying about the entrance which was driven in occasionally by storms, to be washed out again by the ebb-current. Although, no doubt, the actual power of the waves and of the tidal-current to move sands was greater than the ebb, yet, taken continuously, the ebb-current must have the greatest effect, as not only had all the tidal-water poured into the estuary and up the channel of the river to return again, but in addition there was the fresh-water from the drainage of a very large area of land, this ebb-current having also the aid of gravity to assist it in carrying the deposit outwards. There was also a large mass of movable sand in the estuary through which the channel appeared to alter its course from time to time, owing to the prevalence of wind from one particular quarter, or to the influence of long-continued floods. The strength of the ebb-current was dissipated in moving these sands and forming new channels. If instead of having to move these sands laterally, the whole energy of the flood and of the ebb-currents were concentrated in one fixed channel, their force would be employed in scouring and deepening it, and thus improving the low-water channel and giving greater navigable depth at high-water. Any loss of scour due to the decrease in the tidal-capacity would then be more than compensated.

For the benefit of the navigation of the lower estuary, it was no doubt desirable to continue the training-works as originally intended, and so fix a deep-water channel in one course, and there would not seem to be any insuperable difficulty in doing this so as not to injure the channels either to Havre or to Honfleur. There was every possibility that they might be deepened and greatly improved. The line of training recommended by the Author seemed open to the objection that owing to the convex form of the proposed north training-wall, the current would pursue a course along the south side and so away from Havre. The line laid down by Mr. Lemire seemed best adapted for serving both Honfleur and Havre. The partially concave line of wall on the north side would probably draw the flood-tide along it, and the ebb would then return along the same course as being the deepest channel. It would be better perhaps if the concavity were continued further on, to opposite Honfleur, and to let the concavity meet the ebb-current nearer the more confined channel. By thus bringing the influence of the ebb-current to bear more directly on

the channels past Honfleur and Havre, a deep and stable channel Mr. Wheeler. would be maintained, and the zone of sands which now existed in the centre of the estuary as a movable mass, would remain fixed in one position.

Mr. F. WISWALL agreed with the Author that, in point of mag- Mr. Wiswall. nitude, British rivers might not afford opportunities for works comparable with some of those on the Seine; but on the other hand, he believed their capability had yet to be developed, and that they would be found to be at least equal in importance.

The subject of movable weirs had been under his personal observation for some years in connection with the Mersey and Irwell navigation, on which, within the last three or four years, movable weirs had been introduced of a type entirely novel, and which seemed to possess, but in a higher degree, every advantage attributed to the French weirs. This was so whether in regard to their mobility, or adaptability to the different and hitherto frequently conflicting demands of navigation and drainage, or in their power of discharge at the top with a non-liability to silt at the base; or in their indifference to the action of floods, which, so far from hindering, were pressed into service as an aid to the practical removal of the weir altogether; or in their simplicity of action, and independence of intricate machinery; or in the entire absence of a super-imposed bridge or head-gearing of any kind—a feature which was absolutely unique in the history of movable weirs, supplying in flood a navigable pass over the whole width of the river. As to opening or closing the weir, it need only be said that a weir, 140 feet wide and 10 feet deep, could be either put in or taken out of action in half an hour. The extreme cost of weirs of this type already constructed had not exceeded £50 per lineal foot. The tilting-weir, of which those existing at Throstlenest and Modewheel on the Irwell, near Manchester, and at Warrington, on the Mersey, were examples, was designed to effectually impound the water for navigation, to admit of being either slowly or quickly opened as required, and to give a full and free passage to the river when floods or other circumstances made it desirable. The weir (Figs. 8 and 9) consisted when closed of a series of rectangular sluice-gates turning on a common axis; when opened they were suspended horizontally, and each gate was capable of being worked independently of all the rest. Three edges of the gates made a watertight joint, two by contact with each other, and pressure upon the projecting flanges of the supporting pier, and the third edge by resting upon the floor of the weir. The river-bed was laid with a sheathing of

Mr. Wiswall. stone and timber, and was perfectly level. At intervals of 10 feet

FIG. 8.

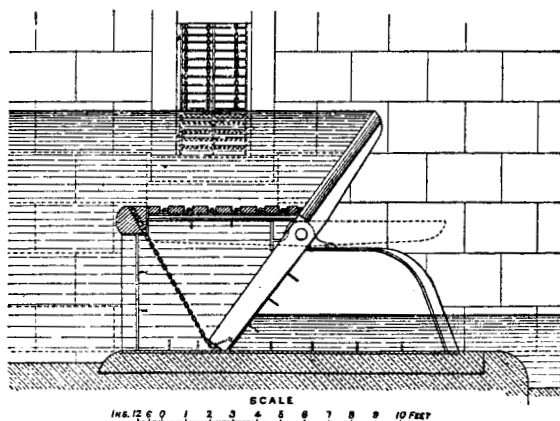
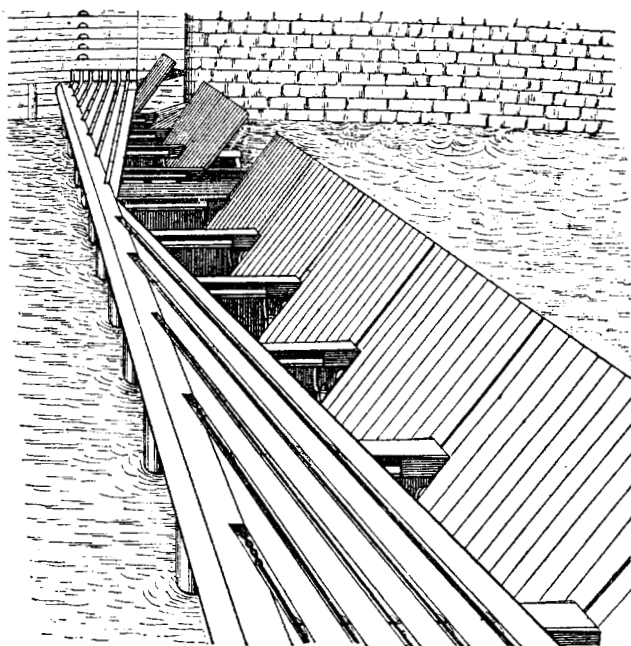


FIG. 9.



from centre to centre, across the bed of the river, cast-iron piers

were erected, with flanges for securing the piers to the river-bed, Mr. Wiswall, and for supporting the tie-beam which extended from shore to shore, and the key-pedestals in which the axle-shafts were set. The turned shafting, on which the gates hung and turned, was in lengths of 10 feet, which reached from pier to pier, terminating in dumb-pedestals keyed to their several seatings on the piers. The gates were framed of English oak, and planked with pine, and were 12 feet long; 10 feet wide above the axle, and 9 feet wide below the axle. A separate draw-chain was attached to the centre of the foot of each gate; it was passed round a grooved pulley secured to the tie-beam, and thence in a straight line to a wall-box, where it was deflected upwards round a grooved pulley to a multiple crab, by which the gate was raised. There were two multiple crabs; one on each side of the river, and each connected with a set of gates. The crabs consisted of sets of three-motion gearing with barrel; that was, one set for each gate-chain. The first motion-shaft, to which the handles were attached, had sliding pinions to enable any one or more of the sets of wheels to be geared to it; the remaining wheels ran loose on the shaft. Rachets were provided to fasten each gate open as it was raised.

The weir had aroused considerable attention in the neighbourhood, and an indication of opinion was obtained from the fact that the Manchester Corporation had decided to introduce two weirs of this type on the River Medlock, as a corrective to the rapid and disastrous floods to which that stream was peculiarly liable.

Mr. VERNON-HARCOURT, in reply to the correspondence, imagined that the greater depth of $13\frac{1}{2}$ feet, secured at high-water neap-tides between Rouen and St. Aubin, than in the river above, inquired about by Sir Charles Hartley, must be due to a desire to provide in this tidal portion a minimum depth, at most states of the tide, equivalent to the $10\frac{1}{2}$ feet which would be permanently maintained in the non-tidal canalized river up to Paris. The greater depth proposed for the navigation up to Paris, as compared with the normal depth of $6\frac{1}{2}$ feet aimed at for the other French waterways, referred to by Mr. Wells, was, he presumed, intended to facilitate the passage of larger vessels, for the important trade between the sea and the capital of France, than could be economically provided for on the other less important lines of inland navigation.

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He thought that answers to Mr. Caland's questions were really contained in the Paper itself. As the tide reached Rouen fifty-eight minutes earlier than formerly (p. 245), it was evident that it flowed up to that extent with greater velocity, owing doubtless to

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the removal of the shoals which originally impeded its progress. Since, however, the tide rose only an inch or two higher at Rouen than formerly, manifestly the limit of its flow could be but little altered, which might be accounted for by the advantage afforded by the deepening of the bed being counteracted by the undue contraction of the channel. He agreed with Mr. Caland in attributing the changes in the tide at Havre mainly to the changes effected in the Estuary by the training-walls (p. 248). Mr. Caland, whilst expressing a general preference for Mr. Lavoinne's scheme, suggested placing the southern training-wall further out into the Estuary opposite Honfleur, which was in accordance with the plan proposed in Plate 4, Fig. 8. Moreover, though Mr. Caland objected to the rapid widening-out of his proposed training-walls towards the mouth, it was less abrupt at the outlet than Mr. Lavoinne's. There was no necessity to contract the channel opposite Havre in order to deepen it, as there was an ample depth there at the present time; but it was very important to offer no impediment to the influx of the tide, and to restrict the tidal capacity as little as possible.

Mr. Partiot's scheme, proposed originally in 1859, and recently published, should have been included in the list of projects for completing the training-works in the Estuary of the Seine, and he was glad that it had been referred to. Mr. Partiot proposed to prolong the training-walls down to Honfleur, and to build out a breakwater from Villerville Point towards Havre, so as to contract the mouth of the estuary to a width of 6,560 feet alongside Havre. Mr. de Coene appeared to agree with Mr. Partiot in the opinion that a restriction of the mouth of an estuary was the proper method for improving tidal rivers; and they quoted the natural configuration of the Mersey, the Humber, and other rivers in support of their views. He was surprised to hear the Mersey held up as worthy of imitation, for he regarded it as most unsatisfactory, with its shallow channels both above and below the narrows (Fig. 7), and peculiarly difficult to improve. Undoubtedly the narrowing of the mouth of the Estuary of the Seine, proposed by Mr. Partiot, would at first promote scour, and increase the depth in that part of the channel, and for a little distance above and below. This contraction, however, would impede the influx of the flood-tide, and cause changes in the velocity of the current through the narrow neck and in the wide estuary above, promoting the deposit of the silt brought in by the tide. This accretion would be greatly aided by the prolongation of the training-walls to Honfleur, so that eventually the greater

portion of the estuary comprised between Tancarville, Hoc Point, and Honfleur, would be raised to high-water level. This large reduction in tidal capacity would reduce the tidal current through the narrowed entrance, and consequently diminish again the depth in the channel. Moreover, this reduction of tidal flow in and out of the Lower Estuary would favour the natural heaping-up action of the sea on the sands outside; so that eventually, not only would the initial deepening of the narrowed outlet be lost, but the good depths in the bay outside the Estuary would be imperilled. He believed that the wandering of the channel, by periodically stirring up the silt and thus preventing its consolidation and facilitating its removal by the ebb, was the only cause which prevented the silting-up of large embayed estuaries like the Mersey. If the channel were fixed by training-walls, or any other means, the Estuary outside the training-walls would remain undisturbed and gradually silt up, till the interior sluicing-basin relied upon by Mr. Partiot for scouring the outlet channel would be lost. He was therefore of opinion that Mr. Partiot's scheme, by restricting the tidal flow, would be only temporarily advantageous to Havre and Honfleur, and would finally leave the Estuary in a less satisfactory state than at the present time.

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It had been suggested by Sir Charles Hartley that the prolonged training-walls should be placed closer together and carried further out than proposed by Mr. Lavoigne, to secure a greater depth; but this would be treating the Estuary too much like a tideless river, and, by restricting the tidal capacity, would be prejudicial to the maintenance of a good depth in front. He agreed with Sir Charles Hartley that the training of the Seine was fully justified by the results, though the lines and widths adopted might have been modified with advantage; and he only considered that the works served as a warning, from the very unexpected amount of accretion which had so rapidly followed, and especially for estuaries whose maintenance almost wholly depended on tidal scour. Sir Charles Hartley and Mr. Fowler had referred to the considerable scour of sand from the bed of the trained channel as greatly affecting the accretion in the Estuary; but, as he had previously pointed out, Mr. Estignard had made allowance for the increased capacity of the channel, so that the volume of accretion given referred to sediment brought in from the sea, and not to material scoured out of the channel.

Though Captain Graham Hills objected to his drawing conclusions from the facts which he had obtained, a duty incumbent on every engineer, he was glad to find that when Captain Hills

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entered himself into the region of speculation, his views as to the clearing out of deposit in the Outer Estuary not being equally effected in the future as in the past, owing to the reduction of tidal capacity, agreed exactly with the opinion expressed on p. 249 of the Paper. He could not, however, endorse Captain Hills' assumption of the injurious effects that would result from the proposed extensions, and that a further contraction of the channel would be necessary. He believed that some reduction in depth might occur in the deeper channels beyond the training-works, but that an equilibrium would be restored before any injurious silting-up took place outside; and that the channel between Berville and the outlet must be much improved by the proposed extension.

The Pointe du Hoc deep, referred to by Mr. Garlick, hugged a convex shore at the present time; so that it might reasonably be anticipated that the tidal influx producing it would run close along the northern convex training-wall proposed. The channel, moreover, of the Seine, as recently as 1880 (Plate 4, Fig. 1), did not follow a southern course; and the accumulation of sand had not extended over the existing training-walls as Mr. Garlick suggested. He could not therefore admit Mr. Garlick's conclusion as to the ruinous effect on Havre, based, as he believed it was, on incorrect premises.

The fact that the training-walls below Tancarville were low walls, had been ignored by Mr. Fowler, though it was very plainly stated on p. 244 of the Paper. Mr. Fowler had also assumed, in spite of the evidence on Plate 4, Fig. 1, that the foreshore, behind the training-walls, in the wide estuary was flat, whereas at a short distance from the back of the walls it sloped up rapidly to high-water level. He was also quite mistaken in supposing that reclamation formed any part of the object of the works; and he might see in Mr. Bouniceau's book how little the accretion was anticipated when the scheme was proposed. In drawing any conclusions from Appendix II, it must be remembered that it only related to the portion of the outer estuary beyond Honfleur, some miles below the ends of the training-walls. Mr. Fowler was quite right in noting that it had been intended to dredge out a channel between the proposed training-walls in the Mersey; but he believed that scour would have effected the deepening, and removed the material to another part of the estuary, before the dredgers could have been set to work. As Mr. Fowler said, the question at issue in the Mersey controversy was whether low training-walls would promote accretion beyond their own height; they had

unquestionably done so on the Seine, and there was an absence of sufficiently exact information to determine what had been the result of the low walls in the Tees, which was the only estuary he knew of where it was contended that no accretion had resulted from training-works. He thought that the exception, if it really existed in the case of the Tees, of which there were serious doubts, should not be accepted as the rule. Mr. Vernon-Harcourt.

The chief criticisms had been directed to the training-walls, which formed the most interesting of the Seine works, because the most uncertain in their results. Though the criticisms differed greatly, he thought that they were valuable as representing every phase of opinion which might be considered in deciding on the question. Wherever the training-walls were extended, fresh accretions must occur behind them; and the difficulty consisted in devising such a scheme that the training-walls should be near enough together to improve the channel down to deep water without unduly restricting the tidal flow. Some engineers objected to training-works as injurious to the tidal capacity of estuaries, which would put a stop to their improvement; whilst others would place them close together to insure a deep fixed channel, which would greatly reduce the tidal flow, and produce a sudden change of velocity of the current at the outlet. The object of his suggested extension was to enforce, rather than to impede, the influx of the tide, whilst regulating and improving the channel in the neutral zone where the influences of the flood and ebb were irregular and deficient.