Discussion.

Mr. Shelford. Mr. W. SHELFORD said there were one or two points to which he should like to refer before the discussion commenced. A friend who had heard that he was about to read a Paper on Non-tidal Rivers, made the remark that fortunately there were not many of them. He appeared to have forgotten that most of the great rivers of the world ran into tideless seas. In Europe, the Volga ran into the Caspian, and the Danube into the Black Sea; in Africa the Nile ran into the Mediterranean; in Asia little was known about the rivers, but some of them certainly ran into the Black Sea and the Caspian; in America the Mississippi, the largest river in that continent, ran into the Gulf of Mexico. But the striking circumstance was that, where ports and large harbours existed in tideless seas, they were carefully put at a distance from the rivers. Marseilles, for instance, a most important port, was some miles from the mouth of the River Rhone, and had thus been cut off from the advantages of the inland navigation. In the case of a tidal river, Marseilles would unquestionably have been on the river itself, or at the mouth. That, he supposed, had arisen from the experience of Rome, the old Romans having, at the beginning of the present era, had a port called Ostia at the mouth of the Tiber, and because it was silted up, and became inaccessible, it was shifted by Claudius to Fiumicino, a distance of 2 miles. The present port of Rome was Civita Vecchia, still further north; it was approached by railway, the navigation of the Tiber being practically *nil.* The diagrams which he had exhibited very inadequately represented the plans and sections from which they were made. Those plans and sections were prepared for the Italian Government by the Commission of 1871, and they were presented to him by the late Mr. Cialdi, of Rome. The Italian engineers and hydraulicians whom he had mentioned were consulted by the Italian Government at the time when the disastrous inundation of 1870 occurred, and might therefore be considered as authorities on the subject. One person whom he had not included in the category was Mr. Vescovali, the present Municipal Engineer of Rome, who had modified Canevari's scheme, and Plate 1, Fig. 5, showed the works which were now being carried out under that modified scheme, prepared from information furnished to him by Mr. Vescovali. The cost of the work already executed, and of the property purchased, had been £1,100,000, and the Italian Parliament was to be asked during the present year for

£2,000,000 more for the purpose of completing the work. Although Mr. Vescovali was concerned in the works, he at first energetically opposed the idea, looking upon the embanking of the Tiber with ornamental walls, like the Thames Embankment, as a palliative rather than a cure, and he had always advocated the straightening of the Tiber below Rome. He did not propose to effect any improvements lower than the point called Ponte Galera, which was the summit of the extremely sharp fall of the flood of 1870. He therefore assumed that, like every other engineer, he had been afraid to attack the outfall. He believed this was the first time that the outfalls of non-tidal rivers had been referred to at the Institution at any length, and he hoped the Paper would prove a useful one. Mr. Shelford.

Sir CHARLES HARTLEY, K.C.M.G., stated that the navigable depth of the channel of the South Pass of the River Mississippi, the opening of which, in preference to the South-West or to either of the South-East passes, he was the first to advocate,[1] from deep water in the main river above the head of the pass to the gulf, was 26 feet, and the width from 240 to 300 feet. Soundings, however, could be taken from one point to the other, giving a depth of at least 29 feet in the Pass itself, and through the jetties of over 30 feet. In the same way at the Sulina mouth of the Danube there was now a depth between deep water in the river and deep water in the sea of 20 feet 6 inches over a navigable channel 300 feet wide, but soundings could be taken between those two points of something over 24 feet. It could not be said, however, that the depth of the South Pass was 30 feet, or that at Sulina the depth was 24 feet, for in both cases the width of channel at these respective depths was insufficient for the navigation. He considered it to be a great triumph for Mr. Eads, considering the difficulties he has had to contend with, that last year seven vessels left the Mississippi with a draught of more than 24 feet, and one of them with a draught of 25 feet 10 inches. Sir Charles Hartley.

With respect to great rivers entering tideless seas, it should be remembered that some non-tidal rivers were comparatively easily dealt with, while others were impracticable. Exposed outlets like the mouths of the Mississippi and the Danube, and outlets like those of the Pregel and the Oder, which before reaching the open sea entered into Haffs or Lagoons, which served as settling basins, might and had been successfully improved; but on the other hand he thought that the improvement of the mouths of

[1] See "Mouths of the Mississippi Correspondence, etc. Clowes & Sons, 1875," in the Library of the Institution.

Sir Charles Hartley.

such rivers as the Volga and the Don was almost impracticable, because the slopes opposite those mouths were extremely flat; the littoral current was almost imperceptible, and the direction of the wind unfavourable to successful treatment. Similar allegations might be made with regard to many tidal rivers entering tidal seas. The river Adour, for example, had hitherto been unamenable to improvement, and the Hooghly would be very difficult to improve, whereas the Thames below London Bridge, and the Scheldt below Antwerp, for the time being at least, needed no serious improvement, and the same thing might be said with regard to other rivers. It would occupy too much time to discuss the relative advantages and disadvantages of tidal and tideless rivers, from an engineering point of view, but it was clear that in both cases the chief aim should be to carry deep water as far up stream as possible, in such a manner as to perpetuate, without undue cost or onerous maintenance, the retention of any increased depth that might once be obtained by artificial means.

With regard to the Tiber, he had had an opportunity of visiting the delta of that river both before and after the flood of 1870, and therefore took a great interest in the question of its improvement, although he knew nothing as to the merits of the plans which had been proposed. It had been stated that nineteen projects had been submitted, and it would therefore be very rash in him to express a definite opinion as to the best mode of carrying out so great an improvement. No doubt the works in progress, part of which he had seen in December last, would give great relief to the floods at a comparatively small cost, but he was not sure that the wisest course had been adopted. Garibaldi's scheme for a diversion of the river outside the walls of Rome, as amended by other engineers, was a much grander one, but the cost would have been much greater, and, as in all such cases, the chief question to be considered was whether the game was worth the candle?

He wished to ask a question with reference to the zero shown on the longitudinal section of the bottom of the river. When he was in Rome he was told that the zero at the Ripetta gauge indicated a level of 1 metre and 17 decimals, about 4 feet, above the level of the sea, and that all the references on the gauge related to that zero, and not to the height above the level of the sea. Consequently the great flood of 1870, which was marked in the Paper at 56·49 feet, should be 60·49 feet. In ordinary dry weather the flow in that case would be 23 feet, and the minimum dry-weather flow would be 21 feet, instead of 17 feet above sea-level.

With reference to the proportion of dry-weather to flood-flows, Sir Charles Hartley.

the maximum appeared to be 1 to 30, which was not very great in comparison with the enormous difference in some other rivers. In the river Ruhr, which flowed into the Rhine, the proportion was 1 to 300; at the mouth of the Durance, before entering the Rhone at Avignon, 1 to 170; and at the mouth of the Rhone itself 1 to 22. The proportion given by Vescovali of dry-weather to the mean flow was large, 1 to 3; in the case of the Danube and the Mississippi it was about 1 to 5; of the Po 1 to 8, if he was correctly informed; so that the larger proportion in the case of the Tiber was, he thought, a favourable element with regard to the improvement of its outfall.

As to the advance of the delta, the Author had given an average of 1·8 yard per annum, so that, taking the time as two thousand five hundred years, the distance was 2½ miles. The advance of deltas, however, was very uncertain; sometimes they were almost stationary, or were even encroached upon by the sea for periods of long duration, at other times they advanced rapidly, and at others slowly. He had visited the mouth of the Fiumara, the large mouth of the Tiber precisely three hundred years after the erection of the tower, St. Michael's, which was built on the seashore in 1569. In 1869 it was 5,520 feet from the sea, giving an average advance of 18½ feet per annum in the direction of the main channel. He believed it had been ascertained that the present advance of the delta between the two mouths was at the rate of 12½ feet per annum. Opposite the Sulina mouth of the Danube and the mouth of the South Pass of the Mississippi the deltas had advanced from 60 to 100 feet annually, whilst the rate of advance of the sandbanks opposite the mouths of the Kilia and St. George's Mouth in the one case, and the South-West and Pass à l'Outre and South-East Mouths in the other case, was more than three times greater than at the outfalls of the improved branches. The most salient angle of the Po and that of the Rhone was advancing at the rate of 220 and 190 feet per year respectively. Compared with these examples, the advance of the delta of the Tiber was very small.

Regarding the slope of the bottom of the Tiber, opposite the Fiumara mouth, and also opposite the Fiumicino mouth, measuring on the Admiralty chart, which was taken from the French chart, he found that at a distance of ¾ mile from the shore the depth was 30 feet. That also was a favourable element in considering the improvement of the outfall of the Tiber. At Sulina at the same distance from the shore, the depth was only 18 feet before the jetties were constructed. The Author had stated that

Sir Charles Hartley. there was an increased length in the river below Rome of 45 per cent., owing to its sinuosities, and that he knew of no tidal valley subject to the disadvantages both of navigation and drainage which that implied. But the length of the Seine between Rouen and the estuary was about twice the distance in a straight line.

He fully agreed with the Author that in river-engineering the fundamental conditions to be studied were at the outfall, but he could not concur in the opinion that with regard to the Tiber the improvement of its outfall would be very difficult, if not impracticable, for want of sufficient water at ordinary times to keep it clear. On the contrary, remembering the advantages of a comparatively steep slope in front of the mouths, the slow advance of the delta, and observing the direction of the currents, and the comparatively large proportion of the dry-weather flow to the mean flow, he thought that the improvement of the outfall, and the regulation of the lower part of the river would not be very difficult or beyond the ordinary skill of the engineer.

It was of course absolutely necessary to consider the relief of Rome from the floods, which did an enormous amount of damage, principally owing to the great amount of silt deposited by them. He visited the Pantheon, for instance, after the subsidence of the flood of 1870, and on going there, partly in a boat, he got ankle deep in mud deposited by the river. He should have liked to hear something about the amount of mud held in suspension, and also about the velocities of the current at the time of the flood and at ordinary times.

There was, however, something else to consider of great importance beyond the question of floods, namely, the provision of a Seaport, either at the mouth or higher up the river, that should be worthy of the eternal city, replacing the present maritime port of Civita Vecchia, which was merely an open roadstead 50 miles from Rome. He was rather surprised, seeing that nineteen projects had been made for the urban part of Rome, that no project had been submitted for improving the lower part of the river, with the view not only of protecting the city from floods but of restoring the Tiber to its ancient function as the great maritime approach to the capital of Italy.

Mr. Maudslay. Mr. HENRY MAUDSLAY said he witnessed the extraordinary flood at Rome in 1870. The annoyance and distress arising from it were very great. There were no boats, and he was hard at work near the Ponte San Angelo making rafts. The only means of getting about in the lower parts of the city was by these rafts, which were formed of doors, or the bodies of wagons placed upon empty barrels. In this way food and medical necessaries were supplied from house to house. The principal obstruction to the flow of the water was the long continuance of the wind in one direction. The winds which increased the bar at the mouth of the Tiber were from the north-west or south-east. Where a river, such as the Tiber, flowed into a tideless sea, a delta was formed which increased to such an extent that the water could not get out. When the waters came rushing down from the Apennines, so great was the flow that fears were entertained that the Ponte San Angelo, which was the first obstruction, would be blown up, cutting off communication between one side of the city and the other, until the subsidence of the water, which covered the approach to the bridge during a day or two to a depth of 15 feet, while the depth at the Ghetto was 30 feet. It was hardly likely that the lower portion of the river could be made navigable unless some new outfall were cut, because in the present condition of the Tiber, the delta would be constantly extending. The Tiber was not tidal; therefore, to prevent inundations, all the obstructions ought to be removed, such as the piers of the old bridge below Ponte San Angelo. In floods the water flowed back into the city by the Cloacas, or main drains, up through the fountains and gully-holes, with all the accumulated filth, thus producing fever, misery, and death. Mr. Maudslay.

Mr. WILFRID AIRY wished to say a few words in explanation of the formula mentioned in the Paper in connection with his name. One or two numerical examples of the meaning of the formula might be given. Taking the case of a stream moving with a velocity of 8 feet per second, that velocity being increased to 9 feet in consequence of artificial works or flood, the formula showed that the increased velocity would move particles of silt of double the weight that it would before. Again, if by any means the velocity of a current could be doubled it would move particles of silt of sixty-four times the weight that it did before, showing the enormous effect of a small increase in the velocity of a stream in removing silt from its bed, or from a bar at its mouth. The formula was an extremely simple one, derived from simple considerations, treated in their simplest and approximate form, but taken as a guide he thought it was quite reliable. The proof was as followed :— Mr. Airy.

Let V = the velocity of a current,
and a = the length of the edge of the largest cube which the current could move.

Mr. Airy. Then, weight of cube $= m\,a^3$ (m const.),
and, friction of cube on bed of river $= p.m.a^3$ (p const.),
also, total pressure of current on face of cube $= q.\text{V}^2.a^2$ (q const.).

For equilibrium

$$p.m.a^3 = q.\text{V}^2.a^2,$$

$$\text{or} \qquad a = \frac{q}{p.m.} \cdot \text{V}^2.$$

Therefore the weight of the largest cube that a current with velocity V could move was $m\,a^3 = \dfrac{q^3}{p^3.m^2} \cdot \text{V}^6$.

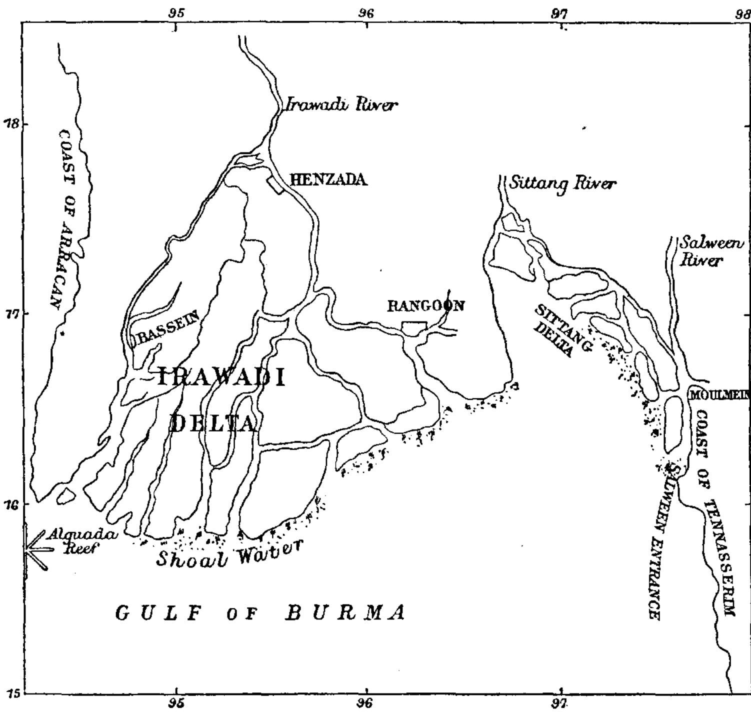
And if W W′ were the weights of cubes of silt, &c., that could just be moved by the velocities of current V V′ respectively, then $\dfrac{\text{W}}{\text{W}'} = \dfrac{\text{V}^6}{\text{V}'^6}$.

Cor. I. If the velocity of a current was increased by $\frac{1}{8}$ part, it would move particles of twice the weight, for $\dfrac{1^6}{(1\cdot125)^6} = \dfrac{1}{2}$ nearly.

Cor. II. If the velocity of a current was doubled it would move particles of sixty-four times the weight, for $\dfrac{1^6}{2^6} = \dfrac{1}{64}$.

Mr. Gordon. Mr. Robert Gordon said Fig. 5 illustrated the formation of deltas in a tidal sea at the north-east corner of the Bay of Bengal. The gulf was formed by the continuation of a mountain chain running underneath the sea, and secluding it from the rest of the bay. Within that region the tide rose and fell, and there were great sea currents. In that small space, about 220 miles wide, there came down three large rivers, two of them ranking amongst the greatest rivers in the world. The Salween had a drainage area of 500,000 square miles, and a course of 3,000 or 4,000 miles. The Sittang had a drainage area of 20,000 miles, and only a short course. The Irawadi had a disputed area of from 200,000 to 400,000 square miles. The Salween discharged 500,000 cubic feet per second in flood. He did not know the amount discharged by the Sittang. The Irawadi discharged as much as 2,000,000 cubic feet per second in high flood. The Salween had no delta, and no estuary. He did not know the rise and fall of the tide, but it was considerable, perhaps nearly 20 feet. The Sittang had a negative delta, the sea rushing in and out, and the whole area usually occupied by the delta being hollow. A series of islands was formed on the eastern side, and no ship or boat could go in, as an enormous bore existed there. The Irawadi also offered curious examples of delta formation. The main body of the water came down in the interior channels, but all those channels had the phenomena which the Author had ascribed to non-tidal rivers. There was a rise and fall of tide of 19 feet at Rangoon, 30 miles up the Rangoon river. On the other side there was another branch, the Bassein River, an estuary of the sea, where the rise and fall Mr. Gordon.

FIG. 5.



of the tide was 10 feet 90 miles up, but in all the other channels, although the tide flowed in and out in dry seasons, no navigation from the sea was possible. There were bars with only a few feet of water over them, and the water overpowered the sea-tides in flood. The delta continued to project into the ocean, and formed a shallow in front of it in the bay.

With reference to Mr. Airy's formula, he might mention that he had experimented on the discharge of the Irawadi for several years.

Mr. Gordon. During 1877 he took the minimum discharge and the greatest flood ever recorded, the measurement being continuous for three hundred and sixty-five days. He measured the quantity of silt carried at the surface, near the bottom, and at mid-depth in the centre of the stream, and the results could certainly not be expressed by Mr. Airy's formula, or anything like it. The river had a rise and fall of about 44 feet at the head of the delta, just where it bifurcated. During the dry weather, when a volume of from 50,000 to 100,000 cubic feet of water was flowing, and the velocity was from 1 foot to 2 feet per second, the mean ratio of the three measurements was 22 parts of silt in 100,000 parts of water by weight. During the greatest flood it was 104 in 100,000 by weight, the difference being as 1 to 5, very nearly in the first power of the velocities, taking from 1 foot to 2 feet per second in dry weather, and from 6 to 8 feet per second as the mean velocity in floods from the surface to the bottom. The amount of silt at the surface, and at mid-depth was very much the same, but near the bottom it was from three to five times greater, and the extreme variation was from 1 part in 100,000 at about 100,000 feet discharge, and 2 feet per second, to 304 parts in 100,000 by weight at very highest flood, which was something less than the cube of the velocities. These measurements agreed very fairly with those of the Mississippi, and of other great rivers in different parts of the world. He did not know what correspondence Mr. Airy's formula had with actual fact; but with the above range of velocities of from 1 foot to 8 feet per second, the eroding and removing force would by the formula vary from 1 to 250,000, instead of 1 to 300. There could be no doubt that the amount of silt carried by the river was a measure of the erosive power of the water itself, for the silt was being constantly deposited and constantly re-excavated from the banks. If the current ceased to excavate, the whole of the silt would be deposited in a short distance, except the very fine silt mechanically held, and that in chemical solution.

The Author had mentioned that there were two methods of improving a river, one by embanking, and the other by straightening and lowering the surface; but the Americans were using another method in the case of the Mississippi, depending on the erosive action to which he had referred. They curtailed the erosive action by lining the banks of the river at the parts where the erosion was the greatest; they therefore, by reducing the eroding action, retained the force of the water, increased the velocity of the current, and thus reduced the cross-section required to carry a certain amount of water. In that way they hoped to make the embanking less. They had carried on this work for some years. He went over 25 miles of this last summer near St. Louis, with Major Ernst, the officer in charge, and they had certainly been very successful. The lining consisted of matting woven in continuous lengths on barges anchored at the spot, and moved down stream as the mattress was deposited. In one case a mattress, over 4,000 feet in length, and from 120 to 300 feet in width, was applied. The banks were shaped, where required, by the hydraulic jet, and rows of piles were driven to secure the mats. Mr. Gordon.

Mr. HENRY LAW thought the point in the Paper of greatest interest, especially at the present moment when such questions were much discussed in reference to the Manchester Ship Canal, was that of the ratio existing between the force and the velocity of running water in regard to the scour. The Author had stated, on the authority of Mr. Airy, that the capability of a stream for moving detritus was as the sixth power of the velocity, and Mr. Airy had given a demonstration of that statement in which he had assumed the particle to be a cube sliding along the bed of the river. Mr. Law had subsequently looked into the matter, and had found that the formula would be equally true if, instead of assuming the cube to slide, it was assumed to be rolled over, which was the more likely mode of progression, and also if the particle was either a cube or a sphere. Adopting Mr. Airy's notation, there was for the moment of resistance to the cube being turned over upon its edge— Mr. Law.

$$\frac{m\,a^4}{2},$$

and for the moment of the force of the current tending to turn over the cube

$$\frac{q\,V^2\,a^3}{2},$$

and as the cube was on the point of turning, these must be in equilibrium, and

$$\frac{m\,a^4}{2} = \frac{q\,V^2\,a^3}{2},$$

and by reduction

$$a = \frac{q}{m}\,V^2.$$

Again, assuming the particles to be spheres, instead of cubes, and that a particle was resting upon three other particles; in

Mr. Law. that case, putting d for the diameter of the sphere, there was for its weight

$$\frac{m \pi d^3}{6}.$$

And if $\frac{d \sin \beta}{2}$ was the horizontal distance of the centre of the sphere from the point of contact about which it had to be turned, there was for the moment of resistance to turning

$$\frac{m \pi \sin \beta}{12} d^4.$$

Then the pressure of the current would be

$$\frac{q \pi d^2 V^2}{2},$$

and the moment tending to roll the sphere onward would be

$$\frac{q \pi d^3 \cos \beta V^2}{4},$$

and when the sphere was on the point of moving

$$\frac{m \pi \sin \beta d^4}{12} = \frac{q \pi \cos \beta V^2 d^3}{4},$$

and by reduction

$$d = \frac{3 q \cot \beta V^2}{m}.$$

Then, as q, m, and β were constant, and the weights of the particles were as the cubes of a and d respectively, it followed that, whether the particles were cubes or spheres, the weight of the particles which the current would be capable of rolling onward would vary as the sixth power of the velocity of the current. That was a startling proposition, but no doubt it was true where the material of the bed of the river was perfectly clean sand or gravel free from all cohesion. When cohesion came into play, as in the case of binding gravel, clay, marl, or rock, the law no longer held good, and then the power of the stream to tear up the bed would be as the square of the velocity. But in that case the depth also must be taken into account, because if a particle of the bed was considered as adhering to the bed, and a rounded surface projecting above, which the water attacked, a particle of water striking that sloping surface would of course be thrown off according to the usual law of deflection. If the water was very shallow, there would be very little resistance to that particle so being deflected, and it would not produce the same amount of work upon the particle cohering to the bed of the river as if the column of water upon it was higher. That, therefore, would account for what was seen in practice—that the scouring power of a very shallow stream running at a very high velocity, was far less than the scouring power of a deeper river running with a smaller velocity. If it was assumed that the particle of water which struck the projection in the bed of the river had not its weight increased as far as its *vis viva* was concerned, but had it increased in consequence of its being held down by the column of water above it, then it would be seen that in striking the particle it produced so much more force, because it could not glance off readily, but was held down and compelled to do its work. The law, however, enunciated in the Paper would have to be modified in the case of bars of estuaries; it applied only in what might be called quiet streams, where there was no other motion than that of the current itself. Under the motion of the waves, the depth came into play, because there was a horizontal motion on the bed of the sea in every case where the depth was not greater than the horizontal distance between the crests of two waves. Where the depth was less than that distance, there would always be a motion backwards and forwards, answering to that of the waves, which would alternately accelerate and diminish the velocity of the current itself, and would affect its efforts in breaking up the bed of the river. Mr. Law.

Mr. W. H. THELWALL, referring to the expression "tideless," said that the Mediterranean was not a tideless sea, though of course its tides were very small. He should be glad if the Author would state what the tides were at the mouth of the Tiber. On the other side of Italy, in the Adriatic, the spring-tides were about 2 feet 6 inches, and in Venice the mean range throughout the year was 1 foot 11 inches; the range of spring-tides 2 feet 6 inches; and the maximum range from the lowest ebb to the highest flood was as much as 8 feet 6 inches. At the mouth of the Po, where he imagined the delta was of the same kind as that of the Tiber, the tidal wave passed up the river to a distance from the mouth of nearly 80 miles, and that must have a very considerable effect upon the formation of the delta. He did not quite understand the distinction drawn by the Author between deltas in tidal and in non-tidal seas. One of the principal deltas in the world was that of the Ganges, in which the extreme range of the tides was about 17 feet. The Author's statement in regard to tidal reservoirs did not apply to the Ganges. When the river was low the water passed up the stream to a distance of 200 miles. In flood Mr. Thelwall.

Mr. Thelwall. times, when the volume of water in the river was very great, the tidal action was hardly felt, the water brought down by the flood being so enormously in excess of that taken up by the tide. The question of the volume of water discharged by the Tiber was a very interesting one, and seemed to have greatly puzzled the Italian engineers, because, as shown by the Author, the difference between the lowest and the highest calculations for the maximum flood in 1870 was 100 per cent., and even when the river was much lower the differences were very great. At low water, when the height by the Ripetta gauge was 5·30 metres, the lowest calculation gave a flow of 95 tons per second, and the highest 190 tons; but again, when the river was in slight flood with a height of 8 metres, the lowest calculation out of seven or eight gave 450 tons per second, and the highest 665 tons. Italian engineers had adopted various methods of determining the velocity by the use of current-meters, floats, and other means; but they all seemed to differ in their results. He would be glad if the Author would state what had been taken by the Italian engineers as the actual volume to be provided for in the new works upon the Tiber. The matter was of course one of great importance, because if the lowest calculation was taken the works might be much too small, and if the highest they might be much too large.

Mr. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt did not think that Englishmen could take the credit of having done all the tidal-river improvement in the world. The improvements of the Seine and the Maas were well-known instances of foreign works, and ought not to be left out of account. The Author had stated that non-tidal rivers had not very often been improved. The general reason for that was, he thought, that the difficulties in improving them would have involved works that had not been deemed worth the expense. In tidal rivers there was a ready means of access from the sea into the interior of the country which tideless rivers did not afford. That was one of the reasons why it was found in the case of tideless seas that ports were not upon rivers, to which the Author adverted after the reading of the Paper, but were generally, as in the case of Marseilles, Algiers, and Alexandria, on the sea-coast. The Author had referred to the formation of deltas, as peculiar to non-tidal rivers, and Mr. Thelwall had alluded to the Ganges as a case of a tidal river forming a delta, but he had plainly indicated how that delta was formed. When the river was in flood it overpowered the tide. That was the time when it formed its delta, and it was then that it was practically a non-tidal river. There were also cases of

Mr. Vernon-Harcourt.

non-tidal rivers not flowing into what were generally understood to be tideless seas. There was the well-known case of the Mississippi flowing into the Gulf of Mexico, which was open to the Atlantic. There was also another case, perhaps more remarkable but not so generally known, that of the Paranà river flowing into the estuary of the La Plata, and from thence into the Atlantic Ocean. It practically formed a delta within the estuary of the La Plata, because there, owing to a confluence of tides, there was very little tidal range. So that on the Atlantic itself there was an instance of a practically non-tidal river outfall. In the case of tidal rivers there was a constant ebb and flow, and therefore almost a constant motion of particles in suspension. Slack water was the time when deposit took place, and that occurred not at one place only, but at several places, according to the state of the tide, and it varied not only at different hours of the day but in different localities, and according to whether it was spring or neap tide. In the case of tidal rivers also, a considerable fall was developed at certain states of the tide; the velocity of the river was at that time increased, and therefore scour took place. Another point of great importance was that in tidal estuaries there was a very much larger volume of water flowing in and out, therefore preventing or diminishing the formation of a bar which was generally liable to form along the coast, owing to the heaping-up action of the sea. The River Mersey, to which reference had been made, was but a very small river in regard to its freshwater flow, which amounted only to about 2,000,000 cubic yards in every tide, whereas its average tidal flow amounted to about 500,000,000 cubic yards, or about two hundred and fifty times the freshwater flow. That showed how important an element the tidal flow formed in rivers of that class. He thought it could hardly be said that it was the tidal flow that acted as the recuperative agent in the estuary of the Mersey. It was rather the shifting of the low-water channel, which maintained the equilibrium of the estuary; for the modifications in the direction of the ebbing current through the unstable sands caused the channel to vary from one side of the estuary to the other. If a fixed channel were formed, up which the flood could come and the ebb tide go down, that large scouring reservoir would be lost, and the bar, or the channel over the bar, would consequently be injured. It was different in the case of non-tidal rivers. They had merely the freshwater flow which descended continuously towards the sea, and as they came into the sea the fall was absolutely obliterated, and they therefore deposited by

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method, though it had succeeded to a certain extent, and had been also aided by means of dredging, had been found not to give a sufficient outlet to the trade of these ports, though adequate in other instances. As in the case of the Mediterranean shores, the Americans, in the three ports he had mentioned, had been recently making harbours by the side of the rivers in the lakes themselves by means of cribwork breakwaters; thus avoiding the river mouths, but not so much because they could not improve the mouths as because they thought it advisable to have more accommodation for trade than the narrow outlets of those rivers would afford. In regard to the Tiber, the Author had submitted two distinct problems. One was the improvement of the outfall, and that he should have thought from the title of the Paper was its main object; but the Author had also brought forward another point common not only to rivers flowing into tideless seas, but to all rivers, namely the prevention of floods. Unfortunately he had not said much about the improvement works that had been carried out at the Tiber outfall. He had stated that there had been some improvement in depth recently effected at the entrance, but he had not given any details about the improvement works that had been carried out at one of the mouths of the Tiber. He had not stated what sediment was brought down by the river, nor what was the slope of the sea in front, which were important elements in the question as to whether the Tiber was capable of improvement or not. He thought it possible that what had been done in the small lake rivers of North America might also be carried out on the Tiber, that the improvement of the river might be helped by dredging. He knew that dredging had proved useless in the case of the Mississippi except within the jetties, but he thought that jetties with dredging might improve the bar in front of the Tiber. He did not agree with the Author that the absence of any suggestions for improving the main outfall of the Tiber indicated that the improvement of its entrance was impracticable, for neither on the Mississippi nor on the Danube had the main outfall been selected for the improvement works. There was also another point that he thought worthy of notice, namely whether it would be possible without considerable works, even if the outfall of the river was improved, to convert the Tiber into a good navigable river? He could only go by the information given in the section, Plate 1, Fig. 2, but he thought it was doubtful whether without very large works it would be possible to improve the river adequately above its delta up to Rome. With regard to the flood flow, it appeared to be backed up at the head of the delta, and the Author

Mr. Vernon-Harcourt. had not mentioned whether there was any impediment at the head of the delta. There was an impediment, and it had to be removed, at the head of the Mississippi South Pass; and it was possible therefore that a bar might be formed not merely at the outfall but at the head of the navigable channel of the Tiber outfall. The Author had also mentioned with regard to the Tiber that as a non-tidal river it was peculiarly meandering. Sir Charles Hartley had mentioned the case of the Seine, the meanderings of which were certainly much greater than those of the Tiber. Including the whole tidal Seine from Havre to the lowest weir on the Seine, the distance in a straight line was 45 miles, but by the river channel it was 95 miles, or an increase of 111 per cent. as compared with 45 per cent. in the Tiber, so that a circuitous course was not a peculiarity confined to non-tidal rivers. With reference to the question of floods, the Author evidently preferred the method of embanking, and no doubt for preserving Rome from floods that might be a most suitable method. But one great objection to embanking rivers for the prevention of floods was that when a river was embanked its bed became, as it were, a place for deposit. People neglected to clear out the bed of the river, trusting to the embankments, and the river continued to silt up; the embankments had to be raised, and unless they were raised to a height above any possible flood, the injury occasioned by very high floods might be as great as that from floods without any embankments. As to reservoirs, he thought that in most cases they did not offer a practicable mode of preventing floods. It might possibly be desirable, at present, to maintain the marshes above Rome as reservoirs for flooding on account of Rome itself; but it would seem the better course to deepen the river below Rome, to improve it also above, to remove the old bridges with their obstructive piers, and rebuild them with adequate waterways, and to straighten the river, as had been done in the case of the Mississippi, and in that way improve the river against floods, not by embanking but by dealing with the channel itself. Such works would also tend to increase the navigable capabilities of the river.

Mr. Redman. Mr. J. B. Redman remarked that in the previous session a Paper had been read descriptive of a tidal river debouching into a tidal estuary;[1] the present Paper was on a river discharging into a tideless sea. On the previous occasion some startling deductions were brought forward; but there were none in the present Paper. The conclusions drawn in the summary of the two classes of rivers

[1] Minutes of Proceedings Inst. C.E. vol. lxxviii. p. 212.

were, he thought, in the main consonant with physics and with experience in such matters. The Paper had a dual interest. First, it directed attention to the fact that the naval supremacy of England, on which it had hitherto prided itself, was in a great measure due to the great range of tide upon its seaboard and in its estuaries. It was secondly of great interest, as showing the physical changes in the metropolitan river of Italy, the "Yellow Tiber," and the efforts that had been made by men who desired the welfare of their country, from the great Roman emperors down to the time of the modern Italian patriot, to improve the river; but with comparatively small results. The Paper had been necessarily historical and retrospective, and references had been given to a large number of memoirs and treatises bearing on the same subject: but the Author had omitted mention of a Paper (antiquated no doubt in some respects, inasmuch as it dealt with the subject as it presented itself forty years ago), by the late Sir John Rennie, Past-President Inst. C.E., "On the Ancient Harbour of Ostia."[1] That Paper dealt with the historical aspect of the question with great perspicuity, and the outcome of it was, that over a period of from two to three thousand years, the progression of the delta was more than 3 miles. It was also curious as showing the progressive change in the Institution, seeing that a Paper devoted to that special subject written by an acknowledged authority of the day, provoked a discussion which induced only two members, in addition to the Author, to join therein, one the late Mr. F. Giles, the other Mr. W. Thorold. Sir John Rennie did not bring forward any special views of his own; but he did theorize to the extent of saying that he thought that when within the capes on either side of the outfall the recession in the line of shore was filled up by the sedimentary deposit, the action would cease, and the outfall would become free. Plate 1, Fig. 7, showed the converse state of things—the delta progressing 4 miles into the sea very much like the shingle promontory at Dungeness, with a very deep bay at each side. In regard to the question of the improvement of the Tiber, the Author had divided the river into sections. As to the outfall, he was inclined to agree with Sir Charles Hartley, that the Author had taken a somewhat pessimist view. The shore was steep, and deep water was rapidly reached. The Author had stated that the principle of leading up the low water of a river into the heart of a country, and thereby developing the scour and Mr. Redman.

[1] Minutes of Proceedings Inst. C.E. vol. iv. p. 307.

Mr. Redman. increasing the navigation, as adopted in this country, was not applicable to the Tiber. Manifestly it was not, inasmuch as there was no low-water and no high-water, but a constant level. But were the outfall deepened by cribwork or auxiliary parallel works on either side, assisted by dredging, and were the great masses of flood-water delivered into a body of its own element, surely the outfall would be proportionately increased in capacity instead of impinging upon a shallow and being deflected right and left and upwards by sedimentary deposit. As to the upper river, it would be remembered that in the inquiry of the Commission of which the Duke of Richmond was chairman, the question was brought forward in regard to the upper valley of the Thames, and the proposition was mooted of applying lateral embankments to the right and left banks of the upper river similar to those adopted for the tidal portion. He had no hesitation in saying that if that mode of procedure had been carried out, it would have been most ruinous. There might not be the same æsthetic objection to such a course in the case of the Tiber; but there was the same practical objection, and manifestly the best mode of improving the drainage capacity of the upper river was by deepening, rather than by raising the parallel embankments.

Mr. Giles. Mr. A. GILES, M.P., said that if one thing had struck him more than another on reading the Paper, it was that Rome, being a city of so much importance that it was once called the Mistress of the World, and which had been in existence over 2,500 years, should have submitted to the constant damage from the enormous floods passing through the city. It did not say much for Roman engineering, although there was abundant evidence of engineering power in the drainage of the city, in the Cloaca Maxima, and in the Aqueducts. There could be no doubt that the plans proposed by the Italian engineers had been decided upon with reference to their cost rather than with reference to their general adaptation to the objects in view. The plan by Canevari, and altered to some extent by Vescovali, appeared to be a step in the right direction; but it would be impossible to judge what the effect of the alteration would be without some comparative cross-sections. It would be seen that the flood-line went over the top of the parapets of the old bridges; and the sections of the flood showed that great dams were caused by those obstructions. The Italian engineer, Possenti, proposed to straighten the river below Rome. It was stated in the Paper that the sinuosities of the river amounted to 45 per cent. more in length than the straight line, and the Italian engineers differed so much as to the results of the proposed straightening, that one of them stated that the flood line would be lowered only 1·8 foot, while another stated that it would be altered 4·92 feet. The question seemed a very easy one to settle, and he could not understand how it was that the Italian engineers could differ so widely. Possenti's plan was to cost £127,000, and, seeing that the government was going to spend between two and three millions in the alterations being made, he thought that the £127,000 would have been money well spent, in addition to that required for widening the channels through the City of Rome. In former times the port was at Ostia, which appeared to have had a life of about 700 years. The encroachment of the delta rather blocked it up, and the expedient was adopted of cutting a canal in another direction to the sea, the life of which being only 100 years, showed, he thought, some bad engineering. He could not help thinking, that if the delta had been taken in hand at Ostia, a new cut would have been unnecessary. It appeared from the section that the height of the flood-line at Ostia above the sea-level was only 11 feet. That would not have prevented a port being made at Ostia, and if proper means had been taken above, the 11 feet might have been reduced to 7 or 8 feet. There were many instances of ports on rivers subject to floods of that height, and he thought it would have been better to have maintained the port of Ostia where it was, than to have attempted a new port. At the same time with a river rising in flood some 64 feet, and with a volume of water rolling down fifty times the amount of its summer flow, there was no doubt a very great difficulty. As a rule, rivers subject to those variations were not so well adapted for navigation as for flood-discharge; this might be further proved by the port of Rome being now fixed at Civita Vecchia, considerably to the north, where there was no river. The Author had stated that tidal rivers had no true deltas, but Mr. Giles did not know what was the difference between a delta and a true delta. There were many examples of tidal rivers which had what he should call deltas—the Mersey, the Dee, the Ribble, and the Tees, for example. A delta, he imagined, meant an accumulation of sand at the mouth of the river; if not, he did not know how a delta could be described. With regard to the sinuosities of the Mersey (Plate 1, Fig. 1), he might mention that the point to the right where the two lines came into one, was simply decided by a ledge of rocks jutting out from the northern shore, and although one line showed an extreme curvature to the south, and another almost to the north, out of twenty plans of directions, made during the last

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Mr. Giles. sixty years, four or five took the course right through the centre of the estuary. As to tidal rivers with bars, it was well known that bars were objectionable. The sections (Fig. 1) showed the difference between the bar of the Tiber, and the bar of the Mersey; but he did not think any one could form an adequate conception of what the bars really were without seeing a longitudinal as well as a cross-section. In the case of a large river like the Mersey, with its enormous commerce, it was remarkable that no attempt had been made to improve the bar. Remembering that sixteen millions had been spent on the Liverpool Dock Establishment, he thought that a million or two more spent in that direction would not be money thrown away. The depth of water on the bar now varied from 9 to 10 feet, but it might probably be increased to 20 feet by proper works. Vessels drawing from 25 or 26 feet sailed from Liverpool; and if a vessel arrived at dead low water, she would find only 10 feet of water on the bar, and would have to wait for three hours' flood before she could get up. At certain times a vessel might have to wait six or eight hours before being able to get in, and that was a circumstance which he certainly thought cast some reflection upon the management of the Mersey. The question of rivers running into tidal seas had been often considered, but the subject of rivers running into tideless seas was a comparatively new one to English engineers, and deserved serious attention.

Mr. Wilson. Mr. WILLIAM WILSON said the Paper related to a subject on which he had always been to a large extent engaged, having had to examine and report upon a great many non-tidal rivers both in Europe and in America. But the chief point of interest to him was the reference to the River Tiber, with which he was intimately acquainted. He was in Rome at the time of the flood in December 1870, and saw what happened when the water rose at the Ripetta to 17·20, being 3·70 above the street, and overflowing all the low-lying districts. He went again to Rome immediately after the flood, and made a careful examination of the river; and he came to the conclusion that the obstructions which caused the floods were encroachments, imperfect water-areas under many bridges, and ancient ruins which had never been removed from the river. He particularly examined the Ponte Trionfale which had been removed, but some piers up to the lowest water-level were standing, and there was an enormous accumulation of deposit behind them. Ponte San Angelo had much too small a waterway. During the flood he observed that the water below was within an inch or two of 2 feet below what it was above, showing that the bridge caused an immense interruption to the flow. Another impediment was the Ponte Rotto, and a bridge with large spans, which had been built upon the same site as two old ones. Two ancient bridges had been removed, one after another, but all the piers existed and caused great obstruction. Another serious matter was that, when the construction of the new buildings began, the builders were allowed to bring their refuse and deposit it over the quays into the Tiber at various points all the way down. He visited Rome on various occasions afterwards, and every time made accurate examinations. In 1875 he went there at the request of the Duke of Sutherland and Mr. John Fowler, Past-President Inst. C.E., to investigate and report upon all the schemes then proposed. Commissioners had been appointed, and at least half-a-dozen schemes had been suggested for getting rid of the obstructions. The principal projects were those of Garibaldi, Gioia, Baccarini, Vescovali, and Canevari. Garibaldi's scheme was to divert the Tiber from near the mouth of the river Aniene, and take it entirely away from Rome for the main discharge. After examining the various projects, he came to the conclusion that Garibaldi's diversion was most undesirable, and there was a strong feeling among the population to the same effect. Garibaldi showed him every attention, and discussed the matter with him. Mr. Wilson persuaded him to re-consider his project, and ultimately to abandon it. He then made his report, which coincided almost entirely with the plan shown by the Author, except that he altered Ponte San Angelo. There was a great desire to keep it as an ancient structure, and he altered it to get more waterway, but he did not put in the works above because he assumed that the alteration of the Tiber below would prevent overflow at the Ripetta. The river now varied in width from 30 to 80 metres, and he proposed that the whole should be made with walls all the way down to a width of 100 metres, all excavated and dredged down to a level of 2 metres below lowest water. The works would cost, according to his estimate, 25,000,000 lire, exclusive of the expropriation of property, which at that time had not been ascertained. He was sure that if the works now going on were carried out, there would be no more such floods in Rome; for the obstructions in the river had more to do with them than the deposit at the delta. Mr. Wilson.

Mr. Darnton Hutton asked for some further description of the bar at the mouth of the River Tiber, of what it was formed, where it was situated, and whether it changed much in height or position? In connection with this subject he should like to say something as Mr. Hutton.

Mr. Hutton. to the difference in the behaviour of detritus of different specific gravities, partly because he had never met with any clear explanation of the point, and partly in the hope of eliciting discussion on it. The two principal forms of detritus which had to be dealt with in rivers and harbours were sand and mud. The specific gravity of sand was about 1·5, and he believed that, excepting when stirred up by storm-waves, it was rarely, if ever, held in actual suspension, but was rather rolled along the bottom by the current. Now if the bottom were as smooth as a billiard-table, and if the particles of sand were perfectly spherical and perfectly concentric with respect to their centres of gravity, they might perhaps move straight forwards; but as the bottom was not smooth, and the particles of sand were irregular, the current pushed them sideways as well as forwards, and the result was a deposit on each side of the line of current. As that side-deposit increased in height the slopes became too steep for the particles of sand to climb, and they were then carried forward to the end of the bank, where they could again escape sideways, thus forming the tailing out of the banks which was to be found in sand-bearing rivers and on sandy coasts, such as the Thames, and the Clyde, and the coasts of Norfolk and Suffolk. He might observe with respect to the motion of the sand along the bottom that he had frequently, when diving in the helmet dress, found it in motion, the top for 6 or 8 inches being very much as Sir John Coode, Vice-President Inst. C.E., had described the surface of the Shambles off the Bill of Portland, but he had never in moderate weather found the sand in suspension. As a general rule sand seldom travelled far; usually it formed lateral banks on each side of the current, and it might be taken as a general principle in designing harbours in sandy localities of no great exposure, that it was well to avoid currents as much as possible. Of course he did not by any means state that as a principle of universal application, because there were probably no two harbours with precisely the same characteristics, and he wished to guard himself against the supposed suggestion of any universal principle, however apparently innocent. At the harbour of Ymuiden, for example, where the principal deposit was sand, the formation of the banks at the side of the currents was clearly shown. The flood tide there ran to the northward, parallel to the shore, at a velocity during springs of about 2 miles per hour, and the ebb to the southward, but at a much less velocity; and when the piers were built the current was diverted, causing a deposit to form almost at once in the outside angles of the piers; but having thus formed, to suit the new direction of the current, the bank had for the last eight years shown no sign of further increase, and might be regarded as permanent. In the same way a deposit tended to form inside the piers alongside the entering current, but there was no sand deposit further up the harbour where there was no current, or rather perhaps he should say, because there was no current there, and the water was less disturbed by the passage of vessels. On the other hand, the failure of the attempt to scour out the channel at the Hoek of Holland, by works very similar to those which had proved so successful at the Mississippi and at the Sulina mouth of the Danube, showed the difficulty of getting rid of such a heavy deposit as sand by means of a current. Mud, however, the specific gravity of which very slightly exceeded that of water, was easily held and easily kept in actual suspension; it was swept along with the current, had less tendency to form side-banks, and deposited slowly over large areas when the force of the current was spent and the water comparatively still. When, therefore, the principal deposit was mud, it was frequently desirable to encourage a current of equable and sufficient velocity in order to prevent deposition. Thus the proposed new harbour at Ostend was so designed as not to interfere with the current of the Scheldt, and it was on that principle that the Mississippi and Sulina works, before referred to, had been carried out. Many sea harbours also, such as Portland, Plymouth, and Cherbourg, owed their freedom from deposit in great measure to their non-interference with existing currents, and it was the neglect of this principle at Flushing harbour which caused the formidable deposit with which it was encumbered. Mr. Hutton.

In speaking of the formation of sandbanks alongside the currents, he had referred only to cases of moderately sheltered situations, and where the sand was uninfluenced by the action of storm-waves and ground swells, both of which would undoubtedly stir up sand from considerable depths, and hold it in actual suspension; and in many cases of great exposure, such for example as Port Elizabeth, more sand was, he believed, moved in one storm than in many recurring tides.

Mr. Baldwin Latham observed that about thirty years ago Mr. W. Hopkins, of Cambridge, calculated that the scouring power of a river was in proportion to the seventh power of the velocity (not the sixth), which was probably as correct in a natural stream as the other was in an artificial channel. He thought that there must be some great error in the gaugings made by the Italian engineers. The Author had not given the figures on his own authority, but on the authority of those who had Mr. Latham.

Mr. Latham. calculated them. It was well known, however, that the quantity of water which would be yielded by a large area of drainage, especially in flood-time, was much less in proportion than that from a small area. In the case of the Tiber catchment-basin the altitude was considerable and the area very large. The average rainfall of the district being given, the means existed of comparing it with the mean discharge given in the Paper and of arriving at the percentage run off from that large area; and when the figures were compared with those of other drainage areas, it was quite clear, having regard to climatological influences which were at work, that there was a considerable error in them. With reference to the Thames, the experience of last year had shown that it had a much smaller minimum flow than had previously been imagined. Allowing for the water extracted by the water companies and passing over Teddington Lock, it could not be taken at more than 9 cubic feet per minute per square mile for the 3,676 square miles above Teddington. The area of the Tiber catchment basin was 6,455 square miles. The average annual rainfall within the Thames basin for fifteen years, 1866–1880, had been calculated at about 28 inches, and it had been shown by Beardmore's careful calculations and experiments that of that quantity not more than 7·8 inches flowed off, and that was probably somewhat in excess of the true quantity. The mean flow of the Thames was taken at 30 cubic feet per square mile, but in the case of the Tiber, the minimum flow was $33\frac{1}{3}$ cubic feet per square mile. Of course the flood-flow could not be ascertained, because there were such various estimates, showing that the gaugings could not have been carried on in a very scientific way. The maximum flow in the Tiber of 5,000 tons per second gave a little more than an inch per day flowing off that very large area, whereas the largest flood known in the Thames through a much smaller area only gave a little less than a quarter of an inch. Again, the maximum flood-flow of the Thames was 360 cubic feet per minute for each square mile, which was 40 times the minimum flow. In the case of the Tiber, the maximum flood was taken at 5,000 tons, which was 1,668·4 cubic feet per minute per square mile, or 4·6 times as much from the larger area of the Tiber as from the smaller area of the Thames. Nothing had been said as to the geological formation of the area, but it might be taken as a principle that when the geological formation was porous, and extremely absorbent of rain, the rain would be given out as perennial water at the low periods, and that those rivers whose watershed had the largest amount of that porous soil would have

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the largest mean flow, and correspondingly a much smaller flood-flow; and impervious geological strata would yield large floods but very little perennial water, and have small minimum flows. But in the case in question, there was an enormous quantity of water flowing at the minimum period, and a correspondingly large quantity in time of flood. That might be so if the grounds were so high that they were covered by perpetual snow, which was melting in summer, but the elevation was not sufficiently great, and it appeared that the great floods had occurred at a time when they were not so much assisted by the melting snow. At the period when the minimum flow took place, all snow would have disappeared from the Tiber drainage area. The facts were simply these. In the Tiber, according to the gaugings, 61·6 per cent. of all the rain flowed off; in the Thames the amount was only 27·9 per cent., and in the Lee 25·5 per cent. The River Seine also gave about the same percentage as the Thames. He therefore thought the figures were over-stated. There appeared to be a notion on the continent that there had been a great diminution of water-supply, and a corresponding increase in the amount of floods in recent years. About ten years ago the Imperial Academy of Science of Vienna issued circulars to scientific bodies to get information on the subject, and he had been recently drawing up a report for a Committee that had been considering the question for some time.[1] Where rivers were constantly extending in length from the increase of their deltas, it was only natural to find that modern floods rose to a much greater altitude than ancient floods; for when a length of 3 miles was added to a river, it would require a much greater fall to discharge even the same volume of flood-water as that which flowed down in former years, and that could only be obtained by increasing the height of the flood inland. He had been collecting statistics in Great Britain, which proved that there was neither a diminution in the water-supply nor any increase in the height of the floods. The highest flood known in the Thames in the present century was in 1809, and the next in 1821, since which time there had been no floods so great as those. Probably river-improvement might have had something to do with this state of things. Since 1821 the highest flood was that in February, 1883. The deltas of rivers discharging into tideless seas, as in the case of the Nile, were due not only to the volume of solid matter brought down, but still more largely to the destruction of microscopic life at the point where the fresh water met the

[1] Quarterly Journal of the Royal Meteorological Society, July, 1885.

Mr. Latham. sea-water. Two-thirds of the delta of the Nile had been shown to be due to the latter cause, and not to the sedimentary deposit moved down the river. So long as those deltas existed and grew, a rise in the flood-water might be anticipated, unless corresponding engineering works were carried out to moderate the work which nature was performing.

Professor Shaw. Professor HELE SHAW asked the Author whether he really meant that tidal rivers had no true deltas? As to the river Ganges, in spite of what Mr. Vernon-Harcourt had said, when it was remembered that its navigation up to a certain distance was carried on to a great extent by means of tides, it would be admitted that it was a tidal river. It had a delta much larger than any of those rivers mentioned by the Author. The Indus also had a large delta, more like that of the Tiber in form. It was 130 miles across, and 70 miles to the head, the tide rising the whole distance. Many other cases might be mentioned, and some explanation of the Author's statement was needed, even with the qualifications which he had given. The Author appeared to give the credit of recuperative power entirely to the flood-tide; but there were cases (certainly many on a small scale) where the cut-offs were made by means of the flood from above. In the Mississippi, he believed, extensive cut-offs were made; the pilots being always on the look out for them. He knew that this kind of action occurred in several small streams. He could not agree with the Author that non-tidal rivers had no such recuperative power. Their sinuosities, it was said, tended to increase in perpetuity; he should like to know a case where that was so. It was generally considered that the sinuosity tended to increase, until the surface slope was so reduced that the velocity fell to a point such that no further erosion took place, at any rate for a time; and the bed did not change until there was some flood, or some out of the way occurrence causing alteration in the channel. As to the statement that the first river-conservancy dated from B.C. 53, that might be technically true as far as the actual appointment of a board of conservators, but it was not the first case of river-conservancy; four thousand four hundred years ago the Chinese rivers were conserved on the most extensive scale. The Hoang-ho, for instance, baffling the skill of many engineers, was dealt with by the whole resources of the Empire, and for a thousand years was carefully conserved. The same had been the case with many other large rivers—the Euphrates for example. The Author appeared to have based his conclusions almost entirely upon the case of the Tiber. Mr. Hele Shaw would contrast it with a river of which he happened to know a little—the Avon at Bristol. The alterations which were made in the latter many years ago comprised the formation of a basin, and the making of a new straight cut, and a floating harbour of 3,500,000 square feet of surface. There was also another cut, and a dam was placed across the old bed of the river at Netham, so that the tide, which formerly flowed up the Avon and the Frome, could not, except at springs, flow further than the dam; consequently a large amount of tidal water had been cut off. He had not found any testimony as to the diminution of the channel below. Although a considerable quantity of the tidal water had been cut off, the scouring power appeared to be sufficient to maintain the channel. A case, though not on the same scale, of a river flowing into a tideless sea occurred in the same neighbourhood. The Gloucestershire Frome, which flowed into the floating harbour so made, it was true, did not, in the highest flood, bring down more than 60 tons in a second; but the point to which he desired emphatically to call attention was that it did bring down a large quantity of water. Some was carried off by a culvert 3 feet 6 inches in diameter, but that was not sufficient to carry off all; a large volume of water passed into the floating harbour, but since it had not much matter in suspension, it did not cause a large deposit, and this was easily kept down by a rudimentary dredging apparatus. On the other hand, where the tidal river, which had a large amount of matter in suspension, came up to the dam, and there became slack water, an enormous deposit took place, sometimes 3 inches in a tide, 6 or 7 feet deep in places on the river in the summer months, and in some places 15 feet had been known to collect, which had to be scoured away by the fresh water coming down in the spring. If it were not for the fresh water coming from above, which left very little deposit, the bed of the river would soon be silted up. Professor Shaw.

Mr. Shelford, in reply to the discussion, said he took credit to himself for having given some prominence to the formula of Mr. Airy, which had been so fully corroborated by the independent calculations of Mr. Law. It must, however, be used with judgment. He had applied it in the Paper to the deposit of detritus as a consequence of diminution in velocity, and he considered this strictly correct; but it did not apply to the transport of silt mentioned by Mr. Gordon, as it referred not to the quantity of silt scoured, but to the size of loose particles, having the same specific gravity, moved or, according to Mr. Law, turned over or rolled by the stream. The following Table showed how this was confirmed by Mr. Blackwell's experiments:— Mr. Shelford.

Mr. Shelford. ANALYSIS of MR. BLACKWELL'S EXPERIMENTS on the TRANSPORTING POWER of WATER at VARYING VELOCITIES (1857).

Description of Substance.	Cubic Contents.		Velocities.		Increase of Contents of Substances moved.	Increase of Velocities.	Sixth Root of Increase of Contents.
	Cubic inches. 1.	Cubic inches. 2.	Feet per second. 1.	Feet per second. 2.			
Brickbats .	2·59	18·5	1·75 to 2·00	2·75 to 3·00	7·14	1·37 to 1·70	1·38
Brickbats .	4·76	18·5	2·25 to 2·50	2·75 to 3·00	3·97	1·10 to 1·33	1·26
Oolites . .	2·39	17·68	2·00 to 2·25	2·75 to 3·00	7·40	1·22 to 1·50	1·39
Flints . .	1·95	10·37	2·50 to 2·75	3·00 to 3·25	5·32	1·09 to 1·30	1·32
Slate . .	2·38	9·06	2·00 to 2·25	2·75 to 3·00	3·81	1·22 to 1·50	1·25

The velocities compared were those at which the substances severally commenced to move.

Several speakers appeared to question his statement that tidal rivers had no true deltas, and the Ganges, the Indus, the Irawadi, and other rivers in the Bay of Bengal had been mentioned by Mr. Thelwall, Professor Hele Shaw, and Mr. Gordon; the Mersey, the Dee, the Ribble, and the Tees by Mr. Giles, and the Seine by Mr. Shoolbred, as examples of tidal rivers with deltas. But Mr. Shelford would rather point to them as instances of rivers such as he had in mind, and would add those which flowed into the Lincolnshire Wash and the Rhine, and reassert that they did not possess true deltas in the sense of a "talus" consisting of detritus brought down by the river and continually extending; but that the outfalls of such rivers were for the most part encumbered by sands, the origin of which was a frequent subject of dispute, and whose deposition, depending upon the forces at work outside, either entirely or to a much greater extent than was usual in tideless seas, was uncertain and abnormal, and distinguished them from true deltas.

The datum of his section of the Tiber had been referred to by Sir Charles Hartley. The zero of the Ripetta gauge had been adopted by the Italian Government Commissioners as the base-line, and they had determined that the mean level of the sea was 0·971 metre below it. This zero, being a fixed and well-known point, was a more satisfactory datum than the sea-level, which was subject to numerous fluctuations, depending on the force and direction of the wind. The amount of suspended matter in the water was as follows:— Mr. Shelford.

River Tiber.—*Extract from the Report of the Minister of Agriculture, Industry, and Commerce.*

Physico-Chemical Observations on the Water of the River Tiber, 1872–1877.

Year.	Suspended Matter. Grams per Cubic Metre.			Suspended Matter. Grains per Gallon.		
	Mean.	Max.	Min.	Mean.	Max.	Min.
March 1872 to Dec. 1872	826·9	28,600	10	57·883	2,002·00	0·7
1874 . . .	1,254·57	21,804	74	87·819	1,526·28	5·18
1875 . . .	1,284·4	42,646	30	89·908	2,985·22	2·1
1875 . . .	1,498	31,008	44	10·486	2,170·56	3·08
1876 . . .	1,112·49	24,634	6	77·874	1,724·38	0·42
1877 . . .	1,158·16	34,027	12	81·071	2,381·89	0·84

and the calculated velocity of the current through the urban Tiber in flood was 10 to 12 feet per second, and in dry weather it was from 1 foot to 1½ foot per second.

In answer to Mr. Thelwall, the Italians had provided for a discharge of 5,000 cubic metres (say tons) per second in the new works in the Tiber.

He thanked Mr. Vernon-Harcourt for the general confirmation of his views on most of the points. The slope of the sea-bottom in front of the outfall was obtainable from the chart (Plate 1, Fig. 3), and might be taken at 1 in 100. The increased length of the Seine due to its meanderings was only a correction to be admitted if the material of the valley of the Seine was alluvial, which he doubted; and he was still unaware of any tidal estuary where the tide was free to act on the soil (as the water of the Tiber was) in which the sinuosities increased the length by 45 per cent.

Several speakers, including Mr. Redman, did not quite seem to appreciate the difficulty of improving the main outfall of the Tiber. No doubt it could be deepened by parallel works and dredging, but when deepened there would be no sufficient volume of water to maintain it, so that the dredging would have to be continuous, particularly as the formation of the bar across the mouth would continue. It would require very flourishing navigation, instead

Mr. Shelford. of two or three floods in a century, to make this expense worth incurring.

Grave doubts had been expressed by Mr. Baldwin Latham about the accuracy of the gaugings of the Tiber, but he had mistaken the amount named in the Paper, and had adopted 5,000 tons per second as the maximum, whereas he should have taken 2,500 to 3,000 tons as the maximum flood-discharge in 1870. This would give about $\frac{1}{2}$ inch per day flowing off the drainage area. The rainfall which produced this was gauged at Perugia, Rome, and Civita Vecchia, and the depth immediately before the inundation varied from 1·41 inch to 2·44 inches in twenty-four hours, and averaged 1·89 inch, so that about 26·5 per cent. was discharged. No doubt three rain gauges over so large an area were insufficient, and the result was only approximate, but there could be no comparison for this purpose between the Tiber and the Thames, as their gathering grounds differed in elevation and strata. He did not attribute the recuperative power of a tidal river to the flood-tide only, but to the combined action of the flood and ebb, though his general observation was that a change of channel in an estuary choked with sands commenced on the seaward side, and this was due to the action of the flood tide.

The case of the Avon at Bristol, which had been referred to by Professor Hele Shaw, had done duty before at the Institution, and belonged to a class with whose characteristics he was familiar, but he could not see its applicability in the present instance.

Correspondence.

Mr. Atkinson. Mr. W. Atkinson observed that the Author contended that in tidal rivers a power was exercised by the flood-tide, which broke through sand-banks, thereby giving a straighter course to the ebb-tide, and that the sinuosities in non-tidal rivers tended to increase in perpetuity. It would be difficult to find an example which so completely contradicted the above as that of the 14 miles of the Parret, taken from its confluence with the Bristol Channel. The direct distance was only 7 miles. The flood-tide, at a part where there was a large sand-bank, did not cut through it, though the flood ran up quickly with a marked head. But what was peculiar and conclusive in this very sinuous river was that, in spite of the tide, its course had been gradually determined by the deposit of the sand, &c., on the flats brought up mostly by the tides. The land-water determined, in this case, the sinuous character of the river