

Mr. WHEELER remarked that since the Paper was written there had been an exceedingly dry summer, and the effect of the sluice on the Witham was more marked than before. After early spring no water had passed through the town of Boston, and the silt had accumulated to a depth of 11 feet, sufficient to prevent the neap tides from reaching the town. Not only was the navigation of the river almost suspended, from the impossibility of getting vessels up, but the whole of the drainage of the Fens was also stopped. The water on the previous day (November 30th, 1868), was just level with the upper side of the doors, and it would require a height of water of 13 feet before the accumulated silt could be carried away. The sluice was situated about 8 miles up the river. When the Fen rivers were in their natural state there was no deposit. Thus, in the Welland, at the same distance from the mouth there was no deposit, and at Spalding, where the tides reached 13 miles up the river, the silt was only 2 feet 6 inches thick, whereas in the Witham the deposit of silt was, as he had stated, 11 feet, all of which would require to be removed before the river was restored to its normal condition.

Although up to the end of October the rainfall had been only about 1 inch below the average, yet May, June, and July were very dry months; and all the rain since then had been absorbed by the Fens, and no water had flowed down the river.

The river Witham was trained between fascine walls as far as Hobhole; beyond that the river ran through shifting sands. The flood tide came up at the rate of about 4 miles an hour for two hours, and drove the silt up to the Grand Sluice. The ebb lasted ten hours, and during that time the silt settled. The accumulation of silt would probably be removed by the fresh water floods in the winter. In 1863 there was a depth of 9 feet 6 inches of silt, and in 1864 of 11 feet, all of which was scoured out by the winter floods. In the Welland there was a back scour of tidal water, but not in the Witham.

Mr. VIGNOLES, Vice-President, said it appeared that there existed, as it were, a struggle between maintaining the drainage of the country and the navigation of the port. He thought it was impossible, at certain distances from the sea, to combine the perfection of drainage with the perfection of navigation: one of the two must yield to the other. There might be a point at which the two could be combined: but, looking at the records of this country and of Italy, where former seaports were now far inland, owing to the accumulations of mud at the mouths of the rivers, he thought it could only be accomplished to a limited extent. In the estuary of the river Witham the drainage had been improved, and thereby much valuable land had been brought under profitable cultivation; but Boston and other ports had suffered, and would probably

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continue to suffer. If the sluice were removed, the tide would no doubt wash away the accumulation of silt, but in other respects its removal would be to the detriment of the drainage. An unprofitable expenditure would be incurred in attempting to improve the navigation to Boston, and the minor channels leading to other places. At present the drainage of the country had been brought to a high state of perfection. He repeated the opinion that the combination of effective drainage and the perfection of navigation were incompatible.

Mr. HEMANS considered the leading principle enunciated in the Paper was, that a sluice was objectionable at the mouth of a tidal drainage river: but many sluices were situated on tidal rivers where an accumulation of silt did not take place, or at least not to the same extent; otherwise it would be impossible to continue the use of such sluices. If the sluices which protected low-lying lands from the inroads of the tide were removed, either the lands must be submerged, or the rivers must be embanked for the whole length to which the tide flowed. In the latter case the expense would probably in many instances be greater than the operation was worth; and as there were many rivers without longitudinal embankments to prevent the encroachments on the land, though there might be embankments on the coast, it was clear that a sluice in such cases was suitable.

Mr. BRERETON said an endeavour had been made to show that the sluice had benefited the drainage, although at the expense of the navigation. But so far from there having been any drainage through the sluice, it had been dammed up for months, and silt had been deposited against the doors, on the outside, to the level of high water of neap tides—a level not yet equalled by the accumulated inland drainage; and the navigation to Boston by the river could only be available for craft drawing a depth of water not exceeding the difference between the levels of high water of neap and of spring tides. To remove from the bed 10 feet or 12 feet of mud by natural scour, the inland waters must rise nearly to the level of high-water spring tides, but the water collected during several months had only reached about two-thirds of that height as yet.

Mr. A. GILES, speaking without personal knowledge of the locality, suggested that, if there was not sufficient scour to remove the mud, the gates should be lifted occasionally at high water, so as to pound a portion of the tide, and be opened at the ebb to let the water out. If the sluice were done away with, considerable expense must be incurred in making the banks stronger, to resist the influx and scour of the tide.

Mr. CURTIS, Vice-President, said the reason why the draw-gates of the Grand Sluice were not opened to allow of the accumulation being cleared away below was that, in seasons of drought, the

water could not be spared, owing to its being required for the purposes of navigation and for the supply of water for irrigating the land.

Mr. R. C. MAY said that in 1853, he constructed the outfall of the Walland and Denge Marshes at 'Jury's Gut,' or 'Jew's Gap,' in Kent, and placed a reservoir or tidal pen, at the sea end of which were draw-gates and at the land end self-acting tidal doors. The tidal water thus penned-in formed a sufficient scour to keep the outfall quite clear. In this case it was not silt that had to be contended with, but the accumulation of shingle and sand which travelled from west to east with the tide on that coast.

Mr. WHEELER remarked that the sluice across the river was, no doubt, the cause of the accumulation of silt. This river was not comparable with the drains in Holland. The sluices erected in Holland were at the mouth: this sluice was 8 miles up the Witham. Of the four large rivers of the district—the Nene, the Ouze, the Welland, and the Witham—the first three, which had no sluices, were in excellent condition. The land above the sluice had been embanked, and the banks had been strengthened by deepening the river; he thought they were quite strong enough to withstand the tide flowing up the river. As soon as there was a head of water above the sill of the sluice of about 12 feet, and he believed it was now nearly at that point, the silt on the lower side of the door would be loosened, and on the doors being opened the silt would be washed away. He had suggested the admission of a certain quantity of tidal water up the Witham. He thought no remedy would be effectual, except the Witham were put in the same condition as the Nene and the other Fen rivers.

Mr. HAWKSLEY, Vice-President, remarked that the Ouze, the largest of the four rivers mentioned by the Author, had a remarkable sluice upon it at a distance of 6 miles or 8 miles above the town of Lynn. It had a peculiar effect upon the régime of that river, which was not stopped up by deposits in the way the Boston river was. He mentioned this because he was desirous that no misapprehension of facts should take place on a question of such importance as the one raised by the Paper.

Mr. WHEELER remarked, that the sluice on the Ouze was a long way from the mouth, and in a different position to the sluice on the Witham. The Denver Sluice had been condemned ever since it was put up. On all artificial drains, such as the Black Sluice, and the other drains on the Witham, which were not tidal streams, sluices were necessary and could not be dispensed with. In reply to various inquiries, he stated that the aggregate power of the pumping engines was 350 H P., and they were under the control of numerous bodies of internal drainage commissioners. If the Grand Sluice were removed, and the training of the river continued

2 miles beyond its present limits, *i. e.*, from Hobhole Sluice to Elbow Buoy, nearly the whole of the engine power, not only above but in the districts discharging their waters below the Grand Sluice, could be dispensed with. The sill of the Grand Sluice was about 5 feet above the present bed of the river at Elbow Buoy, off the Scalp. The ordinary level of the water in the winter would be about 5 feet above the sill of the Grand Sluice, floods about 9 feet, and very high floods 13 feet. The inclination of the surface at ordinary low-water spring tides varied from 8 inches to 1 foot according to the state of the river. The silt began to be removed immediately there was a flow of fresh water. One of the doors had been opened very recently, and the water was now conveying the silt away. In very wet winters, followed by a wet spring, the river would be scoured out to its natural bottom; but, in ordinary winters, a deposit of silt would still remain varying from 2 feet to 3 feet in depth. Heavy freshes would run at the rate of about 3 miles an hour; but the silt was scoured away with a much less rapid current, say 1 mile per hour.

Mr. T. LOGIN believed the facts given in the Paper bore out the theory he entertained with regard to the transporting power of water. He would give a few examples of what he had himself seen in India. In 1855-56 he reported on the navigation of the chief rivers in Burmah, the Irrawadi, and the Sittang. The former discharged its water at the rate of upwards of 700,000 cubic feet per second during floods, and was navigable for sea-going steamers to the frontier, while the latter, which probably did not discharge one-tenth of that volume of fresh water, was so dangerous that on the only occasion of Europeans attempting to enter its mouth nearly all the boat's crew were drowned.

The rise and fall of the Bassien branch of the river Irrawadi was only 9 feet, and of the Rangoon branch 21 feet; whereas the range of tide in the Sittang river was estimated to be from 35 feet to 37 feet between the high-water flood-tide mark in the dry season and low water at the mouth of the river. He attributed the difference in the character of these rivers to the quality of the soil brought down by them, which in the Irrawadi was chiefly mud and in the Sittang sand. He believed that in England, by the extension of cultivation of the land and improved drainage, floods were increased, and carried a larger proportion of soil from the ploughed land into the rivers, and in that way the navigation near the sea was injured.

Some years ago he had noticed a landslip on the right bank of the Ganges, near Rajmahal. The land had slipped down almost 20 feet, but the perpendicularity of a number of palm trees on it had not been disturbed. Again, on the Bassien river, in Burmah, 80 miles inland, he had found a hole 120 feet deep, or upwards of

100 feet below the sea level. Now rivers, such as the Ganges and the Irrawadi, were very liable to change their course, so that what might appear to require ages for its accomplishment might be the work of a single flood. Trees might be found standing 20 feet or 30 feet below the surface, or relics of man 100 feet below the level of the sea far inland: therefore caution should be observed in attributing the finding of these relics—anchors, boats, &c.—to the sinking of the deltas or the upheaval of the land, when the phenomena might be due to the change in the course of a river.

As to the necessity for keeping springs of water below the surface, in the year 1860 he had had the supervision of the irrigation of the Puttree Valley added to his other duties. The natives formerly were in the habit of damming up the water in the streams 10 feet or 12 feet, and causing it to flow over the land; in consequence the spring level was raised. He found that when the level of spring water was more than 18 inches below the surface in years of drought, the crops were benefited by irrigation; but as the water approached nearer the surface, the crops became more and more stunted; and at 12 inches from the surface the crops disappeared altogether and then gave place to grass. Where the water covered the ground, jungle and reeds grew to a height which afforded cover for elephants and tigers.<sup>1</sup>

No doubt the silt could be got rid of, and the navigation of the river Witham be improved, by the removal of the Grand Sluice, but by admitting the tidal water the drainage of the Fens might be endangered. By holding up the spring levels, possibly the same injury might occur as in India, and the Fens, which of late years had been so much improved in climate and cultivation, might fall back into their former state. He would not venture to give an opinion as to how the navigation should be carried out; but he suggested that, if separate navigation was required, the level of the surface of the water in the canal should be below the reduced spring level in the Fens, and that the drainage of the Fens should not be connected with the canal, but passed under it by syphons.

With regard to the annual silting up below the Grand Sluice, he could give a similar example on a larger scale. The Pegu river, which fell into the Rangoon river just below Rangoon, was so narrow at the town of Pegu that, although there was a depth of water in the river during the rains sufficient to float a man-of-war, yet, in turning the steamer, the stern had to be made fast to the bank, to allow the vessel to swing round with the stream; whereas only 20 miles distant was the Sittang, a river 5 miles broad, but

<sup>1</sup> In some parts of this valley an efflorescent salt covered the ground, having the appearance of hoar frost, and rendering the soil barren.

so shallow that its navigation was difficult, indeed dangerous, for boats when the tide was out, even during the rains. A little below Pegu, these two rivers were connected by the Pyn Kyoung creek, through which during the rains loaded boats could pass, but not in the dry season. He took levels in that direction in March, 1856, at which time during spring tides the silt was thrown up to such a height, that at high water of neap tides a cart could be driven over the bed of the creek, which was nearly level with the banks. This was due to the 'bore' which passed up the Sittang every tide, and which he witnessed at the Sittang end of the creek in September, 1855. He heard a distant sound seawards, and a few moments after saw breakers on the horizon, several miles long. In less than a quarter of an hour the water was rushing past at the rate of 9 miles or 10 miles an hour, and the creek was filled to a depth of 11 feet. The tide flowed for about two hours, but did not rise after the first rush of the 'bore' more than 1 foot or 2 feet, and the total rise and fall here was only about 12 feet, but near the sea it must have been much greater. This afforded an example of the silting up of a navigable stream every year, as happened below the Grand Sluice on a much smaller scale. On the Sittang, the current had a velocity of 10 miles an hour, and there was no scour but a silting up of the bed; whereas on the Witham there was a tide with a velocity of 4 miles an hour, carrying with it earthy matter, which was deposited as it gradually came to rest, but which would all disappear again when the fresh waters came down, as observed in Pyn Kyoung creek. He had already remarked that the effect of increasing the drainage was to augment the floods. In such cases the duration of the flood should be lengthened by reservoirs to hold the water up, which might be used for sanitary purposes, or for water power. If used for sanitary purposes, he recommended what was called in India the system of Dhall irrigation; that was keeping the surface water in the channels which conveyed the sewage water always below the surface of the country, so as not to raise the level of the spring water in the Fens; or that the sewage should be conveyed in close pipes under pressure.

Mr. MURRAY stated that the river Witham rose on the northern borders of the county of Rutland about 10 miles south of Grant-ham, and comprised a water-shed between Sleaford on the east and near Newark on the west to Lincoln of about 250 square miles. The waters of this river were divided at Lincoln, and during floods about one-third of the discharge passed northwards by the Fosdyke into the Trent, at Torksey; while the remaining two-thirds were discharged by the Sencil Dyke and the main channel by Lincoln and Boston into the Estuary or Great Wash, a course of about 36 miles. Boston was situated about 4 miles

above this Estuary, and the Grand Sluice was placed across the river Witham in 1762, a short distance above the town, whereby the tidal waters were excluded from the channel between Boston and Lincoln. The late Mr. Rennie, in 1802, proposed raising and strengthening the embankments of the Witham to the city of Lincoln; scouring out and deepening the parts requiring it; rebuilding the locks; and making a capacious cut above Lincoln with draw-gates thereon to carry off the floods. He also proposed to embank the river Till, and to make drains therefrom to discharge its floods into the Witham; and to supply the Fosdyke lock with water, by pumping it from the Trent: thus turning the whole waters of the Witham down its natural channel in the summer season, as well as during floods, for the purpose of keeping the Grand Sluice open, and preventing the accumulation of silt in Boston Haven.

An Act was obtained in 1812, constituting the Company of Proprietors of the Witham Navigation and another body, called the General Commissioners of Drainage. In 1814, the South Delph was formed between Sencil Dyke and Horsley Deeps, but the banks were not completed till 1830 or 1832. The Great Northern Railway Company in 1847 took upon themselves a complete transfer of everything from the Navigation Proprietors: and in consequence of neglecting to cleanse and deepen the channel downwards to the Grand Sluice, the flood-waters were not permitted to run with their proper efficiency. This had been rectified by the works of 1864, as carried out by Mr. Hawkshaw.

He did not agree in opinion with Mr. Hawkshaw, that the Grand Sluice should be removed. A sluice was necessary when the fall and quantity of fresh water of a river was small; otherwise, were the tidal water admitted, impregnated with silt, it would be deposited in its upward course, which the force of the ebb would be unable to remove. He granted that the harbour of Boston might at first be benefited by the greater velocity of the tidal stream to fill the river above; but on the ebb, unless aided by a body of fresh water, and by floods, the effects would certainly not be beneficial between Bardney and the Grand Sluice, and the river below the sluice in course of time would also become deteriorated. He, however, quite agreed that if the outfall below Boston were deepened and properly trained, the most beneficial effects would be produced; and would probably in time enable the lowering of the sills of the Grand Sluice, and the partial admission of the tide through slackers in the gates, retaining the water for a short period after high water, and assisting the tidal scour downwards. This might possibly require gates at the mouths of the subsidiary rivers and drains, to retain the fresh water for the supply of cattle feeding on the lowlands.

In improving the outfalls of the rivers Witham and Welland, it was important to consider the estuary into which they discharged their waters. Lynn Deeps was the natural receptacle of the rivers Nene and Ouze; but it was doubtful whether the former rivers should be trained into it, as recommended in the Norfolk Estuary scheme, which could only be done at great expense; whereas if conducted by artificial means into Boston Deeps, the risk would be moderate, and attended with less cost.

The flood tide of the North Sea ran southward from Flamborough Head nearly direct into Lynn Deeps, where it rose 23 feet at ordinary springs; from thence it ran into the different rivers at the head of the estuary, making the range of flood at Lynn 18 feet, while at Boston the range was only 12 feet. The Norfolk side of the estuary was composed of a mass of shifting sands, while the opposite, or Lincoln shore, had a long tract of deep water running parallel to it, called Boston Deeps, separated from Lynn Deeps by the Roger and Long sands. At the northern end of Boston Deeps there was a bar with little more than a fathom of water upon it at low water. In the deepest part of the Deeps there were 7 fathoms, and opposite to it, in Lynn Well, there was a depth of 27 fathoms. Tidal action alone maintained Boston Deeps. The main set of the North Sea penetrating the shoals lying off the coast between Norfolk and Lincolnshire had scoured out the Inner Silver Pit many miles in length; and the set continued between the Inner Dowsing and Docking banks into Lynn Deeps. Running here with greater velocity than into Boston Deeps, it soon attained a higher elevation, and when the Roger and Long sands were covered, the tide set over them nearly at right angles into Boston Deeps like an overfall. On the return of the ebb, there being no bar to Lynn Deeps, the water fell rapidly, and when the sands were left dry, the water in Boston Deeps found its way to sea over its own bar; hence maintaining this long tract of deep water parallel to the Lincoln shore. It was evident, therefore, that in the present state of things it would be impracticable to warp up this Deep, as proposed in the Norfolk Estuary scheme: and it appeared reasonable that, by training the rivers Witham and Welland into its upper end, no injury would accrue, excepting the possibility of a bar being formed at the point of junction with deep water.

As the outfalls of the rivers Ouze and Nene had been vastly improved, he might be permitted to make a few observations on the works executed on the former river, trusting that some one better acquainted with those of the Nene would explain them. The New Bedford or Hundred-Foot River having been made in 1652, the upland waters of Huntingdonshire were brought from Earith in a direct line to the river Ouze at Denver, a distance of about 20

miles; and as the floods of Cambridgeshire were longer in arriving at the same point, it was necessary to prevent any over-riding of the waters. Denver Sluice was therefore erected in 1653; and then the Lynn people began to complain of want of depth in the harbour. The sluice was blown up in 1713. When it was down the neap tides did not reach Denver, while ordinary springs only rose about 2 feet, the water being lost in the South Level. It was rebuilt in 1746 with a clear waterway of 86 feet, and when the water was at the highest, according to Watté, the sectional area was 1,500 square feet.

The great success of Kinderley's Cut, below Wisbeach, gave rise to another project of Kinderley in 1724, viz. the Eau Brink Cut; but it was not till 1795 that an Act of Parliament was obtained for its formation, and, so great was the opposition to the scheme, that it was not completed till the year 1821. Its length was about 3 miles, while the old circuitous and wide course of the river was about 6 miles. It was widened and improved in 1825. Coincident with the formation of the Eau Brink Cut, Denver Sluice was rebuilt, the sills being laid 5 feet 4 inches lower than the old drainage sills. It had three openings for drainage, each 18 feet wide, and one for navigation, also 18 feet wide. Between Denver and the head of the New Cut, a distance of 10 miles, the bed was scoured to a depth corresponding with the Cut. The effect on the drainage of the country was considerable. By observations made by Sir John Rennie in 1838, compared with those made by Watté in 1791, the low-water line was depressed at Denver 4 feet 2 inches, at the head of the Cut 6 feet 7 inches, and at Lynn Ferry 1 foot 7 inches. In consequence of this lowering of the water surface in the River Ouze, the Middle Level drain was undertaken. It was opened in 1848, with a sluice at its lower end, near the head of the Eau Brink Cut. The drain was deepened to its full extent in 1857. But in 1862 the sluice blew up, and the tide inundated a large district of the lowlands of Marshland.

In 1849 the Norfolk Estuary Bill was in Parliament. It was proposed to make a new cut across the marshes from below Lynn to Howard's Sluice, about 2 miles in length, and to train the river for about the same distance below it, thereby discharging the waters of the Ouze into the upper end of Lynn Deep. Notwithstanding the great opposition to this measure, it was soon afterwards carried into execution. It was made 250 feet wide at the level of low water, increasing 25 feet in width per mile downwards, so that at the level of high water, on leaving Lynn harbour, it was 410 feet wide, and at Howard's Sluice it was 460 feet wide. It was originally 20 feet deep at ordinary spring tides, but the bed had been deepened by natural scour. The effect on the drainage of the country had been great. By observations made in 1855, and com-

pared with those above mentioned in 1838, the low water at ordinary spring tides had been depressed at Denver Sluice about 9 inches, at the head of the Eau Brink Cut 2 feet 9 inches, and at Lynn Ferry 3 feet 9 inches. Thus, by the formation of these two important works, the low-water line had been depressed at Denver Sluice 4 feet 11 inches, at the head of the Eau Brink Cut 9 feet 4 inches, and at Lynn Ferry 5 feet 4 inches, or an average of 6 feet 6 inches.

The fall of the low-water line between Denver			
Sluice and the head of the Eau Brink Cut was			
ascertained to be in 1855	.	.	7·113 inches per mile.
Through the Eau Brink Cut	.	.	3·844 " "
From ditto to Lynn Ferry	.	.	10·400 " "
Through the Estuary Cut	.	.	7·582 " "

Showing that the Eau Brink Cut might still be scoured, or made deeper than it was found to be in 1855.

Mr. CHARLES FROW, of Holbeach, had paid particular attention to the drainage of the Witham; and early in the year 1861 he had suggested a plan for the improvement of the outfall, which was repeated in a report prepared for the Boston Harbour Commissioners in May, 1864, and again in a map of the district he published in 1866, in opposition to a previous project, strongly recommended in 1860, by which it was intended to lead the water from Hobhole Sluice to Clayhole in a circuitous course. The estimate for carrying out this work, for cutting the channel across the Clays and the Welland Outfall, somewhat exceeded £100,000; but he thought it was inadequate, as it would afterwards have been necessary to secure the sides. However, he suggested that the channel should be trained with fascines through the sands, along the west side of and avoiding the Clays, which would cost only £20,000, and for the Welland £10,000.

At that time few people agreed with his views. In fact, the plan, previously projected by the Estuary Company, was generally regarded with favour by the inhabitants of the locality and the Engineers of the day; but now his project was thought so much of, that the Author of the Paper had adopted it.

In the line proposed to be cut across the Scalp Clays, the ground was soft clay to the level of low water; below that there was hard clay difficult to excavate, and it could not be scoured to a deep channel. It was, in fact, the Oxford clay. This was still found at Clayhole at low water, and under the Herring Sand.

In 1864, he was employed by the Boston Harbour Commissioners to report upon the feasibility of maintaining the straight channel he had before proposed; and on making borings he found the depth of sand so considerable, that a channel deep enough for navigation and for drainage might have been scoured by embanking the sides

with fascines, and contracting the current so as to scour away this sand. This was the practice of the district, and answered extremely well; in fact, the Welland had been so treated over a length of 3 miles. The unguided portion of this channel would have been 5 miles in length, and would have led in a straight line to Lynn Deep. Nor would there have been danger of silt blocking the channel. The outfall of the river Lynn passed through a length of 7 miles of sands in which there were no guide banks; yet it had not silted up, and the same might be said of the Nene; and the Witham and the Welland combined would have kept their course clear. At the same time he advocated, as he had suggested in 1861, the removal of the Grand Sluice, whereupon the Boston Harbour Commissioners consulted Mr. Hawkshaw, who agreed that the removal of the Grand Sluice would effect a great improvement, and, in fact, was a necessary work. However, it was not carried out, and centrifugal pumping engines of 180 H.P. were erected in the East Fen, to pump the water from the lower lands into the other portion of the Fen, so that it might pass away over the high sands that were lodged in the river outfall. The levels of the lands where the pumping operations had been applied were, he believed, from 7 feet to 12 feet above the sill of the outfall sluice, so that the Fen might have been drained by gravitation. The cost of the erection of those pumps was likely to delay the removal of the Grand Sluice for want of funds. This sluice was 5 miles distant from the outlet. The flow of the tide up the Welland extended about 15 miles, and in ordinary seasons the rise of the tide was from 3 feet to 4 feet greater than in the Witham; because the admission of tidal water was larger, and the bottom was 3 feet or 4 feet lower than in the Witham, although there was less backwater. If the Grand Sluice were removed, and the tide allowed to pass up the Witham freely, the volume of water would be so much increased that it would thoroughly clear out the sands. It would be necessary to raise and secure the banks of the river for a short distance, and to alter the position of some sluices, to provide for a supply of fresh water and preserve the navigation. The clearing away of the Grand Sluice would insure the drainage of the Fens by gravitation instead of by pumping. Then, again, the constant flux and reflux of the tide would keep the sands lifted by the water in continual motion, and if any did accumulate, the heaviest portion would be deposited first, and in the lower part of the Haven, where they would be removed by every ebb tide. A short time since a dam was put across the river Nene near the town of Wisbeach, which was 10 miles farther from the outfall than the Grand Sluice. Soon the river was comparatively blocked up, though the obstruction was so far distant from the outlet. The dam caused the tide

to 'head' up, and rise higher than formerly where the dam was placed, and, saturating the earth at a higher level, broke down the slopes of the embankments. He advised the removal of the dam, and, after Mr. Page had been consulted, this was done, and the river being tidal for about 36 miles, had reverted to its former condition. It ebbed from 8 feet to 9 feet lower than the Witham in ordinary seasons, taking a point 7 miles up each river; and therefore he contended it would be an advantage to remove the Grand Sluice, when the Witham would be a tidal river for upwards of 30 miles. There was no fear of the banks being scoured away, as the bed of the river was of hard Oxford clay.

The outcrop of the clay formed the eastern boundary of the river Witham, which was prevented passing into the Fens by the ridge, along the side of which it had scoured a channel. This channel could not be maintained at a sufficient depth at the outfall by scour unless it was conducted through the sands. To cut through the Clays, and afterwards to secure the sides, would involve a great expense, and at Clayhole the hard clay was at or near the level of low water; whereas towards the Scalp reach and South Channel the depth of water at low water at a similar distance was from 10 feet to 30 feet. He believed the boulder and other compact clays had determined the courses of the rivers and lines of drainage of the great levels of the Fens. A clay ridge, on which were situated Stickney and Sibsey, divided the West Fen from the East Fen; and he believed the northern drift and clay formed the boundary between the original Estuary and the Fens. In the bed of the Estuary the clay was found at the depth of 100 feet or more in some parts; at Hobhole it was 20 feet to 30 feet below high water; at Clayhole it lay at a depth of about 20 feet only; and at the Scalp, where the cut was formerly proposed, it was slightly above 20 feet below high water, dipping rapidly towards the west and south. The Clays, therefore, protected the outfall; and if, as had been frequently proposed, a cut had been made through them, the natural protection of the outfall would have been thereby destroyed. At Boston, a bed of sand from 1 foot to 3 feet thick rested on the Oxford clay about 18 feet below the surface, and on the sand was a submerged forest. The Author had referred to men's shoes and a smith's forge being found at this level, and from that inferred that the Romans were there at the time the land was at a level 18 feet lower than at present. But the Roman embankments were made ages later. At Clayhole and along the coast of Lincolnshire there was a stratum of peat containing oak trees, and upon that peat in some parts about 18 feet, and in other parts 40 feet and upwards of various deposits, comprising clay, both stratified and unstratified, then peat, clay, and recently deposited sea sand. The northern drift and boulder clays, in patches and mounds,

were deposited on the subsidence of the coast. The boulder clay was superposed by a bed of sand with strata of various clays thereon, and the remains of another forest were found among the strata. Some catastrophe had overthrown all the trees of the lower forest with their heads towards the west; and on it there lay marine and other strata, and again on these another stratum or two of forest peat containing remains of trees of different descriptions. From this it would appear that there had been two or three distinct changes of level of the ground, and he conceived it might be possible, by comparing the quantity of each deposit, to arrive at an approximate estimate of the period of the northern drift and boulder clay deposits. The Roman bank which crossed the parish of Holbeach was considered to have been erected about the year 300. At present there was a breadth of about 7 miles of enclosed marshes in front of that point, so that the marsh had here increased in breadth at the rate of about half a mile in a century; and there was a breadth of about 3 miles of recently deposited sands between the Roman bank and the clay deposits. These clays were variously composed, and at a different tidal level; and the calculation led to the inference, that it was at least thirty thousand years since the last change in the relative levels of the land and the tidal waters of the Estuary. Previously the prevailing deposits were clays, not sands as at present. Taking this as the basis of calculation, he thought that the periods of the forests and of the northern drift deposits might be traced approximately. But at the same time this formation of marsh land showed that the sea-wall of the Romans was built upon the present surface, and not 18 feet lower, as implied by the Author.

He had ascertained, by taking levels, that the lowest lands in the Fens up the Witham were about 7 feet higher than corresponding fen lands up the Nene, at equal distances from their respective outlets. Yet the lands by the Nene were drained by gravitation, while the higher lands by the Witham were drained by pumping, at an estimated cost of £3,500 per annum. The necessity for this might fairly be attributed mainly to the Grand Sluice stopping up the river; and the defective state of the outfall caused the drainage by sluices discharging into the lower parts of the river Witham to be obstructed.

For comparing low water at the outfalls of the rivers Ouze, Nene, Welland, and Witham, tidal observations had been taken at about 13 miles above the confluence of the rivers in the Estuary, and, after being reduced to a common datum, 100 feet below Ordnance datum, were as follows:—

1866, November.	Ouze, Free Bridge.	Nene, North Level.	Welland, Fosdyke.	Witham, Black Sluice.	Witham, Hobhole.
	Feet.	Feet.	Feet.	Feet.	Feet.
Average . . .	94·43	95·13	99·75	103·83	100·42
Maximum . . .	96·75	98·12	100·25	104·90	101·25
Minimum . . .	93·50	94·48	99·25	103·00	99·67

From this it would be seen, that the level of low water in the Witham was nearly 9 feet higher than in the Nene, whereas it might be at least equal, as local circumstances were more favourable for the Witham.

For calculating the respective rates of fall per mile in each outfall, low water was assumed on an average of tides to be 90 feet above datum at a distance of 7 miles from each of the tidal gauges. At the confluence of the rivers low water probably averaged 86 feet above datum at spring tides. This would be equal to a flow of 28 feet at spring tides at the Gat channel. An average of three months' observations gave the following results:—

Name of River.	Extent of Tidal Influence, and remarks.	Rate of Fall per Mile.
	Miles.	Feet.
Ouze . . .	40, back-water abundant . . . . .	0·63
Nene . . .	35, back-water rapid in winter only . . . . .	0·73
Welland . . .	15, very little back-water . . . . .	1·50
Witham . . .	5, approaching Nene in back-water . . . . .	1·97
Ditto . . .	Might be 35 . . . . .	(Might be equal to Nene.
Ditto . . .	From and below Hobhole in a length of 3 miles . . . . .	

Mr. JOSEPH TAYLOR remarked that the Grand Sluice had been built across the head of a tidal and navigable river, but during the greater part of the year there was no ingress or egress of water through that sluice; he was, therefore, not surprised to hear that the channel had been silted up to a depth of 7 feet or 8 feet below it. Moreover, the silt could not be removed until the doors of the sluice were opened, and the doors could not be opened until the silt was removed; consequently the silt was stirred up with poles, and in time it got away. But if any sudden flood occurred while the sluice remained closed, it would probably lay the country above the sluice under water. The effect upon the navigation was ruinous, and he imagined the drainage interests were not much better served. As the sluice was inoperative for the greater part of the year, there must be a great deposit of silt. If it were taken away, the silt removed by dredging, and the bed of the river

lowered as much as it would admit of, he saw no reason why the condition of the river for navigable purposes should not be much improved, and at the same time a freer course be left for the drainage waters; and looking to the interests at stake, as affecting the port of Boston, he thought it was a matter which called for immediate attention.

Mr. REDMAN observed that Boston Sluice was built under no less an authority than Smeaton. Smeaton, Langley Edwards, and Grundy reported upon Boston Harbour in the year 1761. The arguments of Smeaton, at that time in favour of the erection of the sluice, were of a similar character to those made use of at the present day in favour of its retention. It was stated plainly that the primary object of the sluice was to keep out the tidal water; the natural consequence was the deterioration of the town of Boston as a commercial port. It was manifest that great changes below Boston must have occurred, when it was recollected that at no very remote period of the history of this country Boston rivalled the metropolis in its shipping trade, and that, as recently as the year 1720, vessels of from 250 tons to 300 tons could discharge at the quays. Undoubtedly many of the sluices in the Fens had been to a considerable extent influenced not only in design but in circumstances by the works carried out by the early projectors; and the design of Vermuyden was to lead the water to the best possible outfall for the landed interests of the district alone, and to exclude the tide, and this had been followed by many of his successors. It was to be borne in mind that the late Mr. Rennie proposed a sluice across the Nene below Wisbeach. He did not think the decadence of ancient Italian ports upon a tideless sea bore any analogy to the decadence of British ports where the tidal range was large. Thus, in Boston Deeps, the range of spring tides was from 20 feet to 25 feet, while there was a depth of only 12 feet of water at the sluice: either the sluice must exercise an injurious influence upon the Estuary, or the tortuous and difficult character of the Estuary itself had led to these results. There were harbours not far distant from Lynn, as, for example, Wells and Brancaster, which had been kept open by the natural agency of the tide alone. Rye Harbour, on the Sussex coast, was an instance analogous to Boston; and there also the same Engineer recommended a like expedient with similar results. That harbour was undoubtedly sacrificed to the landed interest. The tide was excluded by the Scott's Float Sluice, which was blown up about the same period as the Denver Sluice. The erection of the sluice caused some commotion at the time; and although attempts were made to prevent its re-erection, and even to destroy the works as they proceeded, it was rebuilt, and had stood to the present day. A large area of valuable land was reclaimed, but the harbour suffered greatly. Smeaton indorsed

that work, and himself designed certain works in connection with it.

The Author of the Paper referred, in support of his proposal, to the unobstructed outlets of the Ouze, the Nene, and the Welland. Reference had also been made to the Denver Sluice; but that was not a parallel case to the Boston Sluice, as it was 7 miles up the River Ouze. The early decadence of Lynn Harbour had been by some attributed to the Denver Sluice: when that was blown up there was the same desire, as had been mentioned in the case of Rye, to prevent its reconstruction; and there were reports at the time by Mr. Walker and Mr. Mylne upon the effects which they alleged would take place from the removal of Denver Sluice, and developing the tidal range above. Mr. Redman could not quite agree with the deductions drawn by Mr. Murray from the facts he had brought forward with regard to the destruction of Denver Sluice; for though when in ruins the tide possibly did not pass above, had the sluice works been entirely removed, and the river developed above, the results would have been very different. The early decadence of the port of Lynn had, to a certain extent, been forgotten, owing to the recent modern improvements of its river. The Ouze (Eau Brink) Cut, conjoined with the new lower cut to the north of and below the town into the Wash, had so improved the river that the effect of the Denver Sluice on its early condition was, to a certain extent, forgotten.

Mr. HAWKSHAW, Past-President, said, he had reported on several occasions in 1861, 1862, and 1864, on questions of importance to the district; but he had found it impossible to induce the various parties interested in separate objects to act in concert for carrying out a comprehensive scheme of improvement. There was no difficulty in greatly improving the harbour of Boston, provided the wealth and commerce of the place were sufficient to justify the necessary expenditure, and provided the money was found for doing it. Boston was formerly a good harbour. It was now very bad, and was getting worse every year. As to the suggested measures for its improvement, he was surprised to hear it argued that it would do no good to remove the Grand Sluice. Consider, for a moment, what would be the effect on the port of Liverpool of constructing an embankment across the Mersey, just above the docks, and putting in a sluice there, and then a pretty accurate opinion could be formed of what had been the effect of the Grand Sluice at Boston. It was not the quantity of fresh water only that had to be taken into account—indeed the volume of fresh water in the Mersey was small; but he believed, if the sea were admitted 20 miles or 30 miles above Boston, it would necessarily tend to improve the harbour. Other questions had, however, to be regarded. The land-owners on the River Witham wanted fresh water for their cattle,

and not salt water, and they objected to salt water flowing up into the country. That was a local difficulty. Then, again, to remove the Grand Sluice and to carry out the works proposed, whether the cut were taken to Clayhole or to the Maccaroni channel, the cost would amount to £100,000, and there was no such sum available. Mr. Frow's estimate of £30,000 was altogether inadequate. He had quite lately, at the instance of those gentlemen who first consulted him, carried out the minor scheme included in his report. As they could no longer suffer their lands to be overflowed, he had built a sluice across the river into which they drained, and had erected powerful pumping-engines which lifted the water at the sluice 5 feet, and gave an artificial fall to that extent. These gentlemen could not be expected to have their property ruined, because they could not induce people to combine together for the improvement of the Boston navigation. In like manner he had advised that the river Witham should be deepened and widened above the Grand Sluice; and that work, which was good as far as it went, was now being carried out; and if all those interested could be induced to combine together at some future time, perhaps it might be decided to take away the Grand Sluice, and carry out the further works for improving the harbour of Boston, and with which the improvements at present in progress on the Witham would be in nowise inconsistent.

Mr. W. SHELFORD thought that the construction of the Grand Sluice was a mistake in principle, which could hardly be justified in practice. He was for some time in local charge of the works on the Nene for Mr. Fowler. In 1856 a dam, similar to the Boston Sluice, was constructed in the tideway of the Nene, 3 miles from Wisbeach and about 14 miles from the sea. Passages were left for the fresh water, and there were slackers on the up-stream side to dam back the inland water for navigation and irrigation. Two years and a half after the dam was completed, the river had silted up to a considerable extent for some miles downwards, and the port of Wisbeach was damaged. The remonstrances of the inhabitants against this being of no avail, a mob attacked the dam and destroyed it in one night; and he was himself roughly handled in attempting to defend it. After the dam was destroyed, the effect was very remarkable; whereas, before its destruction, there was a gradually increasing quantity of silt on the up-stream side of all obstructions in the river: three days after its removal, he observed that the deposit was being rapidly removed from the up-stream to the down-stream side, showing that the removal of the dam had restored to the ebb tide its preponderance of power over that of the flood; from which it would appear, that if it was desired to keep a river of that class open by tidal scour, the free oscillation of the tidal wave must not be interfered with.

[1868-69. N.S.]

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It seemed to be thought by Mr. Murray that the Grand Sluice ought to be retained, and that if it were removed it would not effect any improvement, because there was a want of fresh water in the Witham. But he thought the question of the comparative value of tidal and fresh water was involved in this, and that the want of fresh water might even have justified the erection of the Grand Sluice. In such rivers the tide came in largely charged with silt, which was deposited in time of drought at the head of the tidal influence where the ebb tide was then weak. That went on from day to day until a freshet came down from the uplands and carried the silt into the tidal reservoir, whence it was scoured out to sea. He believed the navigation of the Nene, the Ouze, and the Welland might be made superior to the Witham, if there was no fresh-water reservoir at its head. He thought the point at which the introduction of fresh water was most advantageous was at the head of the tidal influence, and that it gradually diminished from that point to the outfall, where it was of no value.

The difficulty of reconciling the conflicting land and drainage interests of the district had been referred to by Mr. Hawkshaw. So far as the engineer was concerned, he thought the case might be, and had been, met in this way; the full flow of the tide might be admitted, the effect of which would be favourable to the navigation, and the low-water line might be lowered, thus giving a natural outfall for the drains. The irrigation interests would be provided for by constructing a canal or drain from the upper portion of the river, so as to bring the fresh water down in a smaller channel through the district to be irrigated, giving it an outfall into the original river, at some lower point.

Mr. BRUNLEES considered, from his knowledge of the Witham, and from his experience in dealing with other sandy estuaries and rivers, that the Grand Sluice was a drawback to the district, because so long as the flux and reflux of the tides and their scouring influences were retarded, the deposit of silt in the haven below the sluice must increase; thereby limiting the navigation to vessels of small draught, and preventing the free discharge of the land water, and a sufficiently low level for the drains of the large district which had the Witham for its outfall.

It had been proposed to divert the outfall of the Witham through Clay Point to Clayhole. This would no doubt improve that river, but the Welland, diminished in volume, would be left to struggle through a long run of sands, and would be liable to be gradually silted up. He therefore contended that the Witham and the Welland should be united at as high a point as possible, much as nature had indicated by their present position, and that when these streams were fixed and trained their united powers would maintain a good outlet.

Notwithstanding the Author had shown an intimate knowledge of the subject, and his suggestions for the improvement and outfall were thoroughly practical, there was still a large question untouched—the reclamation of the land which should follow on the fixing of the channels, and he thought it would be well if the present Paper were supplemented by another on the reclamations in the Estuary.

Mr. HAWKSLEY, Vice-President, said, he would take the opportunity of suggesting what appeared to him to be the change of circumstances under which it might now become desirable to remove the Grand Sluice at Boston. There was no doubt, that, at the time the Grand Sluice was first erected, it was the proper thing for an engineer to do, because the landed interests, and particularly so of that neighbourhood, were then much more important than the commercial interests. Nevertheless, it must be confessed, that the result was highly detrimental to the port of Boston. The effect had been to cause a considerable silting up of the harbour of Boston, and of the channel leading to it; and there could be no doubt that if the Grand Sluice were removed, and if the tide had a free run up the river to Bardney Lock, Boston Deep, the harbour of Boston, and a large portion of the Witham itself, would be much deepened, and vessels would be able to come up to Boston of a size which now could not approach that port. But many difficulties would present themselves in carrying out an undertaking based upon that idea, which did not appear to have been fully anticipated in the Paper which had been read. It must be borne in mind how essential it was to keep the salt water out of the Fens; for not only was it necessary to remove the excess of fresh water—which consisted of rain falling both on the Fens themselves and flowing from the higher lands which descending to the Fens, and caught by the catchwaters, was by them ultimately delivered into the fen drains and passed to the sea outfalls—but it frequently happened that the rainfall in the Fens was below the amount of the summer evaporation; and that, consequently, the Fens required to be fed by the admission of other fresh water obtained from the river, in order to maintain the level of what was locally called the 'Sock;' and that if that fresh water were not admitted, vegetation would suffer, and it would become impossible to maintain the cattle in the fields. A considerable difficulty would obviously arise in maintaining this supply of fresh water if the river Witham were to be again converted into a salt-water channel.

At the time the river Witham was changed from a salt-water channel to a fresh-water channel, the alteration was effected with the view of supplying the Fens with fresh water for the purposes of vegetation and of the breeding and feeding of cattle, as well as to

facilitate a system of communication by internal navigation instead of by roads which then scarcely existed; and up to the present time, undoubtedly, the effect of the engineering of that day had, in these respects, been perfectly successful. He did mean to say that, by such a change, if it should be considered essential—and possibly it might now be considered essential—the ports on the east coast in which the tides were now dammed back by sluices could be improved for commercial purposes to the general benefit of the country at large. This, however, would not be accomplished without many accessory engineering works needing to be established to prevent the serious injuries to other interests to which he had alluded. It was quite clear, if salt water were admitted up the river Witham, that it would be necessary, not only to maintain special sluices upon all the side drains which were now connected with that river, so as to exclude the salt water as far as possible; but it would also be necessary to bring down a supply of fresh water from the upland country at a point above that to which the salt water of the tide could possibly reach in the driest periods. That would be a work of considerable difficulty, not perhaps in an engineering sense, but in consequence of the small quantity of water which was to be found in the upper part of those rivers. The stream in the river Witham above Bardney Lock was in a dry season scarcely worthy of being called a river at all; and the Fens, on the wetness of which so much was said on a former occasion, were at this moment being mainly fed by the water which had been gathered in the early part of the spring. Therefore, the simple engineering works, which were suggested as being consequent upon the removal of the Grand Sluice, would not alone be sufficient for the prevention of great damage during years of serious drought—such years, for instance, as 1864, and during a portion of the summer of 1868, and on some other occasions, when indeed the rainfall of the whole year had been reduced to as little as 16 inches—a fact which would no doubt appear surprising to many engineers, whose experience had lain on the west side of the kingdom, but which was perfectly well known to those engineers who had become practically acquainted with the fen districts of the east coast.

Then, with regard to the important question which arose respecting the relative level of the land and the sea in the present age, and in former, and perhaps in future ages, he was perfectly satisfied himself, and he thought philosophers of the present day had come very generally to the same conclusion, that the whole of this country, in common with a large portion of Europe, was being slowly but gradually tilted; and that the effect of the tilting was that for the most part England was gradually descending, and more particularly on the east coast. On the other hand, there

could be no question that the eastern part of Europe, from the Baltic far into the interior of Russia, was all slowly ascending. If that were the fact, and he firmly believed it to be so, and geological examinations of recent date tended to that conclusion, it would suffice to explain the many anomalies which had been stated to exist in the course of this discussion.

Mr. ABERNETHY remarked that, for some years past the drainage of the district had been deteriorated, mainly because the outlet of the river Witham had silted up, and unfortunately there had not been sufficient accord between the parties interested in the navigation and drainage to enable the latter to have due consideration. About three years ago he found, opposite Hobhole Sluice, a considerable shoal, several feet above the level of the sill; this affected the whole of the drainage, and at that time a Bill was brought into Parliament to empower the erection of a pumping station near the eastern marsh to transfer the drainage from the upper to the lower fen district. If the present system were continued, the lower fen district, having no sufficient outlet, must become deteriorated to a great extent. If, as had been proposed, the river Witham was deepened at the Scalp, and the channel at Hobhole Sluice improved, by excavating the bed to the level of the sill, so that a thorough outlet would be made into the river, there would be no occasion to drain the upland district at the expense of the lower. Unless there was complete accord between the parties interested in the navigation and drainage as to deepening the main outlet of the river, he was confident the whole of the drainage would gradually deteriorate from year to year.

Mr. T. MARR JOHNSON said, with regard to the straight outfall proposed by Mr. Frow, with a view of joining on with the Ouze outfall, it seemed to him that there would be no present advantage to be gained by such a plan. It could not be effected, except at enormous cost, until the reclamation of the sands adjoining had been much advanced, and the chance of reclaiming these was very remote. He believed the Wash had only been diminished by about one-fourth of its area since the time of the Romans; at that rate, it would be several hundred years before the existing sands were so far enclosed that the outfalls could be economically brought together. He thought there were disadvantages in attempting to combine the two channels, inasmuch as by so doing the errors attributed to Vermuyden would be repeated,—not giving separate outfalls to the districts into which the Fens were divided, thus inducing perpetual quarrels amongst the drainage interests. He presumed that the main object now was to improve the outfall of the Witham; but, inasmuch as the distance to sea by Mr. Frow's proposal would not be sensibly diminished, the inclination of the bed would remain practically as it was at present. The mainte-

nance of the training banks across the sands east of the Maccaroni Channel would be very costly, and there would be a most awkward junction with the Welland.

Taking into consideration the difficulty in getting funds for the improvement of the Witham outfall, he could not help regretting that something had not been done to aid the Lincolnshire Estuary Company, in their proposal to reclaim large tracts of salt marsh on the left of Boston Deep. This Company, like the Norfolk Estuary Company, was saddled with an Act of Parliament which, although invaluable to the drainage interests, was not of much use to the shareholders, on account of the heavy obligations attached to it. In the first place, before an acre of this marsh could be reclaimed, a new outfall had to be made for the Witham, and another for the Welland. Then the new outfalls had to be maintained, by the removal of the existing shoals, and by the clearing away of any others that the works might cause. The Company had also to pay for Admiralty inspections, together with the cost of surveys to be made to find out the obstructions caused by their works; and to enclose nearly the whole of the existing salt marshes included within their limits free of expense. Another large breadth near the sea was to be enclosed at cost price. Further than this, roads 30 feet wide had to be constructed, and all these things had to be done before an acre of land became the property of the Company. Hampered with such onerous conditions, it was impossible that the Company could proceed with the project. But if the drainage interests had combined, and had given proper aid, either by taking up a proportion of the shares or by granting subscriptions adequate to the benefits to be received, there was no question that the two interests would have reaped incalculable advantage, by the improvement of the outfalls and of the drainage and navigation up to Lincoln.

He was curious to know why slopes of 4 to 1 had been selected for the proposed outfall cut. It was the same slope as that prescribed for the Norfolk Estuary Marsh Cut; but although an attempt was made to form that cut at slopes of  $4\frac{1}{2}$  to 1, and of 4 to 1, those slopes could not be maintained. In the cases of the Ouze, the Nene, and the Witham, the slopes varied from  $1\frac{1}{2}$  to 1 to 3 to 1. The Eau Brink Cut was 3 to 1. The Witham, where unprotected, was  $2\frac{1}{2}$  to 1; where protected with fascines, about  $1\frac{1}{2}$  to 1.

He took some tidal observations in the Witham, for Mr. Fowler, six years or seven years ago, and found that high water rose 8 inches higher at the Grand Sluice than at the outfall. There was no rise to compare with that in the Ouze or in the Nene, where no sluices obstructed the tide. It would be interesting if the Author would state whether this same rise of 8 inches existed under the altered

condition of things ; viz., the shoaling of the river, near the Grand Sluice, as described in the Paper. With regard to the removal of the Grand Sluice, so much had been said on that subject, that very little remained to be added. He thought that no efficient natural drainage could be completed while that sluice remained. He did not apprehend any difficulty with regard to the fresh-water supply ; neither did he believe there was a great deficiency of water in the upland district. The obstructions to the free discharge of water into the Witham at Lincoln were so great, that the lands above were constantly inundated, and the drainage was most imperfect at all times, and much of the water was diverted or wasted. He knew of one instance in particular, in the Western district, where an outlet of 16 feet was provided for in the Act. This was construed to mean 16 feet area, and the consequence was the drainage of the whole district of 5,000 acres or 6,000 acres was dammed back, until the water of the lower districts had passed off. If the waters of this and the adjoining districts were properly regulated, there would be a good supply of fresh water down the Witham in times of drought : and he did not see any difficulty in preserving at least the same quantity of fresh water as there was at present. The principle upon which this supply might be preserved, in case the tide were allowed to flow freely, might be thus described :—A side cut might be constructed from the head of the tidal navigation upwards which should be the means of maintaining the navigation, and which would also be a fresh-water channel and reservoir. From this channel, or reservoir, fresh water would be distributed by drains, and occasional syphons, into the local drains. It was merely a question of size of reservoir, and therefore quite easy to maintain as large a supply as the watershed yielded. The local drains should be of much larger capacity, both for the sake of holding the fresh water during the time of high water, to be discharged at low water, and for containing the fresh water for the supply of the districts during droughts. He thought this storage of water was somewhat lost sight of in drainage matters. He did not consider it was more difficult with this river than with others. No doubt the want of unanimity of interests was the great difficulty in the present case. Land-owners in the Fens were mostly enterprising and pushing, and when it was found impossible to accomplish drainage operations by combination, engines were erected even at the risk of drowning the lands of less enterprising neighbours ; and having once established engines, it was not surprising that there should arise an indifference about combination, which, however much it was desired in the first instance, could only then be a source of unnecessary expense. Hence combination became daily more difficult. He did not see any other difficulty in so improving

the Witham, that the tide would flow up to Lincoln. The tide in the Ouze flowed  $37\frac{1}{2}$  miles; and the distance from the mouth of the Witham to Lincoln was only 41 miles. He hoped before the occurrence of some great catastrophe by the bursting of banks, a useful combination would be brought about, and that these works would be carried out upon a comprehensive plan, for the benefit alike of the navigation and of the whole area of valuable land now so imperfectly drained by the Witham.

Mr. WHEELER observed, in reply, that the discussion had related principally to the erection of the Grand Sluice and its effect. He had mentioned in the Paper that the Witham was a river 68 miles in length, draining a tract of country of nearly 700,000 acres of land; and that across this river, at a distance of 8 miles from its mouth and within about one-third of the distance of the natural run of the tidal wave, the Sluice had been erected. This Sluice was a construction so arranged with self-acting doors, that while allowing the fresh water to flow through, it completely barred the progress of the tide. The result was that the flood tide, which passed over extensive beds of shifting sands, entered the confined part of the river charged with a large amount of mud held in suspension, and flowing up at the rate of about 4 miles an hour, was suddenly stopped in its course by this sluice. In two hours the tide had reached its height, and then gradually settled down again. In summer, when there was little water passing off the land, and consequently no stream of fresh water down the river, the tidal water for a time remained almost stationary, and retired very gradually. There was no back current of any force, and the heavy particles of silt and sand brought up in suspension had time to settle by their own gravity on the bed of the river. The deposit which thus accumulated varied according to the state of the summer, from a depth of 3 feet up to, in a very dry summer like that of 1868, 10 feet or 11 feet, in fact to such a depth as to shut out the neap tides altogether; and this remained until the winter, when the upland waters came down in sufficient quantities to scour it out again, and remove it to the Estuary. In a very wet winter, followed by a wet spring, such as 1866-67, the river would be scoured out down to its natural bed; but in ordinary seasons a great part of the deposit remained. (Plate 8, Section.) The effect of this deposit, both on the drainage and also on the navigation of the port, was most serious. He ascribed it entirely to the erection of this sluice, and he might say, that the time which had been occupied in discussing this point had by no means been thrown away, because, if he was correct, the example of this river might act as a warning to engineers who had rivers to deal with under similar circumstances. Had the effect of this sluice on the Witham been more generally known, it was possible that the attempt to

place a similar dam across the Nene, above Wisbeach, would never have been made, and the cost of the works would have been saved to the Commissioners. On the other hand, if the inference drawn from this discussion were that a sluice so placed was beneficial in its operation, then an example had been given which could be repeated in other situations. But he thought that the weight of evidence, and the tendency of the remarks, not only of those who had taken part in the discussion, but of all the Engineers, without exception, who had specially considered the matter, when called in to report on the drainage and navigation of the district, was decidedly against the sluice. Mr. Rennie, Mr. Telford, Sir John Rennie, and, more recently, Mr. Hawkshaw, had, one and all, pronounced the sluice to be a great mistake. Such being the case, the question had been asked, why was this sluice ever erected? and why was it now allowed to remain? To answer the first part of this question, it was necessary to go back at least two hundred years, when the attempt was first made, by the Duke of Bedford and the other adventurers, to reclaim the great Bedford Level. They employed, as their engineer, Vermuyden, who came from Holland, where large works of reclamation had been already carried out, but on lands lying contiguous to the sea itself, and not having natural rivers passing through them. Under such circumstances the only practicable course to pursue was the one adopted,—to make artificial cuts and protect them at the end by sluices. Unfortunately, Vermuyden failed to perceive the difference in the circumstances of the country he had left and that to which he had come. The Fens of the great Bedford Level were intersected by large natural rivers, which formed the main channels for carrying off the drainage waters. The obvious course that ought to have been pursued, would have been, first, to have attended to these outfalls, by embanking their sides and straightening their course, and then leading the fen waters into them by such new cuts and drains as might be necessary. Instead of doing this, and aiding and improving the works of nature, Vermuyden ignored the rivers and made long straight cuts. These being made through the porous soil, and for want of a continual current, soon filled up; and then other cuts and fresh drains were made, and unnecessary works executed at great cost and loss to the adventurers, who found, after spending enormous sums of money, that they were in little better position than at starting. Doubts were entertained at the time as to the effect of this system of internal drainage, and Westerdike, another Dutch engineer, was sent for by some of the adventurers who felt dissatisfied. He at once condemned Vermuyden's plan; but in spite of this it was still persisted in, which could only be accounted for by the jealousy which had ever existed between two sets of Commissioners, who ought, on every consideration, to have

acted in concert. The adventurers of the Bedford Level saw that, by improving the outfall of the rivers, they would be giving material assistance to the Port of Lynn, and rather than do this they tried every imaginable plan to make their own works effective without touching the outfall. At length the conclusion forced itself unwillingly upon them that this was an impossibility. Their proceedings were analogous to those of a farmer who, having a field of very wet land on his farm, should proceed to drain it with tiles, without providing an outfall, by scouring and cleaning out the ditches; and then, when he found his drainage ineffectual, should keep on adding more drains, while the ditch into which they were to empty could not discharge the water brought into it, owing to its neglected and foul condition. It was not until every other plan had been tried that, at last, those extensive works for the improvement of the outfall—the Eau Brink Cut and the new channel below Lynn—were commenced, the carrying out of which had such a beneficial effect on the whole drainage of that portion of the Fens, and by which 280,000 acres of land had been benefited, but at a cost of £600,000.

The unfortunate example set by Vermuyden was followed up in the other districts, and it was only with great reluctance, and after large sums of money had been wasted in abortive attempts, that the Drainage Commissioners finally found themselves compelled to improve the outfall of the Nene below Wisbeach, and the Welland from Spalding down to its outfall. On these three rivers the Commissioners of Drainage had then found, notwithstanding the use of steam power, and every other plan, that the rivers which nature had provided were the natural outfall for their water, and that no drainage operations could be effective, unless these were put in the best possible condition to allow of the passage of the water; and that although, in improving these rivers, they might be serving other interests than their own, yet after all it was their best policy, in fact, their only alternative. Here, then, was the secret of the difficulty the engineer had always presented to him in dealing with matters of fen drainage, and led to the necessity for that caution in giving an opinion which Mr. Hawkshaw had been obliged to use in drawing up his reports on the Witham. The question asked of the engineer was not what was the best plan to pursue, but what plan could be devised that could be carried out, independent of all other interests, which should effect that object without benefiting the neighbours. It was this feeling that had assisted materially in retaining the Grand Sluice in its situation, and had caused the rejection of every plan that had been suggested to the Witham Commissioners by all their engineers for the improvement of the outfall. Mr. Rennie tried every argument in his power to induce the Commissioners to commence their works

of improvement on the lower part of the river, and there was scarcely a report of his on the Fens extant in which reference was not made to this subject: but hitherto all such advice had remained unheeded, and the Commissioners declined spending any money out of their own dominions. No doubt the Drainage Commissioners, by the removal of this sluice, would materially improve the navigation to the port of Boston, and so benefit the town; but, after all, by so doing they would be really benefiting themselves. Boston was entirely an agricultural town. It existed solely as a mart, where the produce of the country round was brought to be exchanged for articles of merchandise required by the growers of corn and meat. It had no extraneous manufactures; the few large establishments that existed were entirely for the supply of the wants of the farmer, such as oil-cake manufacturers and agricultural implement makers. The more cheaply the transit of merchandise could be effected between the town and country, and the town and the rest of England, the more profitable must it be to the farmer. For instance, the cost of sending corn by rail to the places to which Boston merchants chiefly consigned it was about three shillings per quarter; whereas it could be sent by ship for one shilling. Owing to the state of the river in the summer of 1868, ships could not be got up to the granaries, and the corn was obliged to be sent by rail; and this loss of two shillings, being the difference in the cost of transit, must fall on the farmer. So with coals, and the ordinary articles of daily use and luxury. Attempts had been made to run a regular service of steamers between London and Boston, whereby all heavy goods could be imported at much less cost, but the state of the river prevented it. A firm in the north had built a screw-steamer on purpose for the Boston trade, but after using it one season, owing to the state of the river, it was obliged to be withdrawn. Large quantities of foreign oil-cake were imported from the Baltic and Marseilles, and of linseed from Italy and Odessa. When the river was in order the ships could come up to the merchants' warehouses and discharge their cargoes. Now every cargo of cake had to be brought up in barges at a cost of £40 to £50, which compelled the merchant to sell the cake at a higher price to reimburse himself. It was clear, then, that the interest of the port and of the Drainage Commissioners in this case were one; and that the removal of this sluice would add to the general prosperity of the district.

There was one other reason to which he had not yet alluded, why this sluice should originally have been erected? At that time the only means of transit for merchandise and produce into and out of the Fens was by sea and by the inland rivers. In erecting this sluice it virtually made the Witham a canal, and

facilitated the passage of barges and other boats to all places between Boston and Lincoln, and thence by the Fosdyke and Trent to all the midland parts of England. But this could remain no longer as an argument in its favour, as the railway had almost entirely superseded the Witham as a means of transport for the inland towns, and the navigation had become quite a secondary consideration.

The banks had only recently been both heightened and strengthened, and were above the reach of the highest spring tides. And if there were the least apprehension of danger from extraordinarily high tides, the plan could be tried of leaving the doors of the sluice open to all ordinary tides, and closing them against the highest of the spring tides, which would no doubt give sufficient back scour to keep the river free from deposit.

As to the objection that the salt water would impregnate the land on either side of the river and injure the cultivation of the crops, he might say that there were numerous examples of tidal rivers passing through similar strata which did not in the least suffer from any such ill effects, and it was only necessary to point to the lands below the Sluice and bordering on the Wash and the other tidal rivers to dispel the idea. To another objection, that it would injure the wells and deprive the residents of their supply of fresh water, no doubt there would be some inconvenience from this; but the residents on this river would then be in no worse condition than those on other tidal rivers: besides, owing to the leakage of the salt water through the doors, not only on the Witham but on all the other main drains in the Fens, the water in the summer for several miles above the outlet became so brackish as to be unfit for use.

A more serious objection had been urged, as to the deposit that would be left by the tide at the extreme end of the tidal wave. This no doubt was a matter for consideration, but yet the effect produced by this was only slight and temporary compared with the deposit which now took place; and the first run of fresh water down the river would remove it, while such deposit as did take place would be so high up the river as not in any way to interfere with the navigation. On the Welland this deposit, at 13 miles up the river, had been only 2 feet 6 inches thick, as compared with 11 feet in the Witham. On the Ouze, about 30 miles up the 100-foot river, and 18 miles above Lynn, the deposit reached sometimes as much as 4 feet in thickness; but it rapidly disappeared, and in all these cases it might be reduced almost to nothing by continuing the training of the river still further through the sands into deeper water.

Finally, the strongest argument in favour of his view of the subject was the fact that, with regard to these four rivers draining large tracts of fen lands, one had a sluice across it, and a river full of

deposit stopping both the drainage and navigation; the three other rivers had no sluices and had no such deposit, the navigation was unimpeded and the drainage was much better than on the Witham. For although, as had been remarked, there was a sluice on the Ouze, it had been explained that this bore no resemblance to the Grand Sluice, being situated 10 miles above Lynn, and the tides having an uninterrupted course up the 100-foot river. Denver Sluice had had a most injurious effect on the Ouze, and had been a subject of controversy ever since it was built. He did not wish it to be supposed that he considered sluices in all situations a mistake, quite the contrary. At the end of all artificial cuts emptying into tidal rivers, or arms of the sea, sluices were absolutely necessary, to prevent that silting up which would take place from the want of fresh water to remove the deposit at the end of the tidal wave, and which would therefore increase year by year until the whole channel was silted up. Where, too, a river debouched into an arm of the sea, or into deep water, the erection of a sluice might be the means of saving many miles of embankment, and as, in such a situation, there would be no danger of deposit, there could be no objection. Again, where for the purposes of canal navigation a sluice or staunch had to be erected across a stream, to change a river into a canal, if this were done where the current was only downwards, and the obstruction was beyond the reach of the tidal wave, the objection no longer held good. But these were all different situations to the sluice in question, which was so placed as to interfere with the natural flux and reflux of the tide, and which, if its channel were only properly regulated, would always have a beneficial influence in scouring and cleansing and keeping it free from deposit; and every effort ought therefore to be directed to increase the length and duration of the tidal wave, and so to add to its force and scouring power.

One other point in the Paper had attracted attention, the best method to be adopted for training the outfall of the Witham and the other fen rivers into deep water. Mr. Murray had referred to the Norfolk Estuary and the other schemes for reclaiming portions of the Wash, and had expressed the opinion, that these schemes must prove unsuccessful if carried out. But he differed from that opinion. The Wash was rapidly and visibly silting up. He could state, from his own personal knowledge, that the whole of the foreshore was rapidly encroaching on the water, low water line being now in some places from 2 miles to 3 miles distant from the old Roman banks, and there were numerous 'intakes' all along the coast, showing the extent to which the land had warped up. The sands also in the middle of the Wash, called the Long Sand, the Roger, and the Bar Sand, if rightly drawn on the Admiralty chart and the Ordnance maps, which were made from surveys forty or

fifty years ago, were also increasing in height and extent. Where on these charts a large space was shown between these sands, with depths of water sufficient for a boat to pass through, all was now filled up and the sands almost joined. This silting up he attributed to the alluvium washed away from the east coast, and brought by the tide into the bay; it was a matter meriting the greatest attention as affecting the efficiency of the outfall of the rivers which debouched into the Wash, rendering their training a never-ceasing work. The training completed at great expense at one time might put the drainage in a thoroughly effective condition, but in twenty years' time perhaps, owing to this silting up of the Estuary, the outfall would again become defective and again require pushing forward into deep water. Most comprehensive schemes had from time to time been brought forward for taking advantage of this accreting process, which if they had been carried out, the greater part of what was now sands and water would have become valuable land. The first was that of Kinderley, who proposed to warp up the whole of the bay. In 1839 Sir John Rennie brought out a scheme for training the four great rivers into one outfall and reclaiming 900,000 acres of land at a cost of £3,000,000; and as he estimated the value of the land when fit for enclosure at £6,000,000, this plan would have redeemed from waste a tract of land as large as a county, to the great profit of those who carried it out. The scheme was mainly taken up at the time by Lord Hardwicke, who was then, he believed, Chairman of the Bedford Level Commissioners, and other large landed proprietors, and several meetings were held in London; but the difficulty of procuring the necessary capital at the time, which was one of panic in the money market, prevented its further prosecution. He had no doubt that if the system of training these rivers with fascine work, pushing them on gradually into Lynn Well, were pursued, the land on either side would rapidly accrete; and if Sir John Rennie's plan had been carried out, it would long before this have been quite fit for embanking, and worth £50 an acre at the least.

In 1851, another scheme of a less extensive character was brought out, with Sir John Rennie and Mr. Freebody as Engineers, termed the Lincolnshire Estuary Company, for training and uniting the rivers Witham and Welland, and enclosing 30,000 acres of land. An Act of Parliament was obtained, but difficulties arising from sufficient powers not having been taken to settle the claims of the frontagers and others, the powers of the Act had been allowed to drop.

Now, if any comprehensive plan of this kind could be carried out, he thought there was no doubt that Lynn Deeps was the proper outfall for the waters of the Witham; but in default of this, to attempt to train that river through the beds of shifting sands

that intervened between its present outfall and Lynn, would require an expenditure of money that no benefit that could ever ensue would justify the parties interested in that river in incurring. With regard to the plan referred to by Mr. Frow, who proposed to do all this training for £30,000, he considered that that sum would hardly be sufficient to pay the preliminary expenses, and he thought when it was considered that to carry it out the river would have to be trained through 5 miles or 6 miles of shifting sands, and have to run directly across the tidal current coming up Boston Deep, a most difficult and hazardous undertaking under any circumstances, every one at all acquainted with such work would fully endorse this opinion. Failing any comprehensive scheme, therefore, the obvious place for the outfall of the Witham was into Boston Deep, and the place which had hitherto found favour, and which had been recommended by Mr. Hawkshaw, had been by making a direct cut across the Clay Scalp into a place called Clayhole. The advantages of this plan would be very great; the objections,—the cost and the separation of the Witham from the Welland, unless the managers of that river would continue their training to rejoin the Witham which they had not the funds to do. Another alternative, alluded to by Mr. Brunlees, appeared likely to answer every purpose, and it could be effected at a fourth of the cost, by following the present course of the water, but confining it to one channel, by continuing the fascine work from its present termination to a point 2 miles lower down to the confluence of the two rivers. The fall of the water at present between these two points was from 2 feet to 3 feet per mile, owing to the water continually varying its channel amongst the sands; but by the training, these sands could be fixed, and in time become capable of cultivation, and the fall would then be reduced to what it was in the other rivers—from 6 inches to 8 inches per mile—or a lowering of the water in flood times at the sluices of from 3 feet to 4 feet, or more than the difference between the flooding of the fen lands, or their effective drainage. It would cause the waters also to discharge at once into a channel with a clay bottom, and so remedy, to a great extent, the evil now caused by the silt being carried up the river. For the bottom along the whole of Boston Deep, at any rate the upper part, was clay. And it would possess this further advantage, that if ever any more comprehensive scheme were carried out, the river would not have been diverted from its natural course, but the work now proposed would only require further extension.

Boston Deep was nearly as good a channel for discharging the waters as Lynn Deep, there being very little difference between the time of ebb and flood in either channel. He understood Mr. Murray to say, that the tide set into Lynn Deep and then passed towards the north over the sands into Boston Deep. But in point

of fact the time of flood tide in Lynn and Boston Deeps was almost coincident. A vessel lying in Boston Deeps would swing round about the same time as the Lynn Light Ship, occasionally varying with the state of the wind. The tide in Lynn Well would be a little before that in Boston Deeps; but the utmost advantage in favour of the former would be from a quarter of an hour to twenty minutes. He stated this not only from his own recent observation, but from conversation with the pilots of the port. Possibly it might have been different some years ago, before the sands reached their present extent, because now at nearly high water there certainly was a set of tide from the west towards the main on the north side of the Deeps; but at present, although it was true there was a bar at the exit of Boston Deeps, yet the flow of tide into Lynn Well had little or no advantage in time.

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December 8, 1868.

CHARLES HUTTON GREGORY, President,  
in the Chair.

The discussion upon the Paper, No. 1,147 "Description of the River Witham," occupied the whole evening, to the exclusion of any other subject.