Associate Members—continued.

HENRY DAVID ALEXANDER REID.
ERNEST JAMES RUMSBY.
HERBERT BLOMFIELD SMITH, Stud. Inst. C.E.
HUBERT LE GAY SOLLY, Stud. Inst. C.E.
FRANCIS JOSEPH EDWARD SPRING.
JAMES JOHN TALMAN.
FREDERICK HERBERT TULLOCH, Stud. Inst. C.E.
JAMES WALLACE, Stud. Inst. C.E.
RICHARD JOHN WOODS, B.E., Stud. Inst. C.E.

Associates.

THOMAS BRIDGES HEATHORN, *late Capt.* R.A.
THOMAS MCILWRAITH, LL.D.
JOHN FREDERIC MAIN, M.A., D.Sc.

(*Paper No. 1829.*)

"The Conservancy of Rivers: the Eastern Midland District of England." [1]

By WILLIAM HENRY WHEELER, M. Inst. C.E.

THE conservancy of the rivers of this country is a question continually growing in importance. It is one which must before long be dealt with by Parliament, and legislation effected which will necessitate considerable engineering works for putting the arterial drainage of the country on a more satisfactory footing. The frequent recurrence of floods, and the immense damage caused by them, cannot be allowed to go on without a remedy being sought.

Much valuable information as to the best method of forming a proper organization for the management of rivers has been elicited by Parliamentary Committees and public discussions on the subject, and individual engineering opinions have been given as to the way in which Floods Prevention Works should be carried out. No opportunity, however, has yet been afforded for a general expression of engineering opinion and discussion of the principles on which the regulation of rivers should be conducted. Such a discussion will be highly valuable, not only to those members of the Institution who may hereafter be called upon to carry out these works, but also as a basis for the guidance of those on whom lies the responsibility of deciding the best course to pursue, and of levying the money to pay for the works. From want of a clear perception of the principles which ought to guide all works for the improvement of rivers, great mistakes have been made, enormous sums of

---

[1] The discussion upon this Paper was taken together with that upon the succeeding one.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

money have been wasted, and taxes levied from which little or no benefit has been derived.

The circumstances of river basins in this country are so various in character, owing to geological and economical causes, that it is not possible to lay down any method of dealing with all rivers alike. Still there are certain general principles that should prevail, and which should be borne steadily in mind in designing improvements, whether of a local or a general character. In the following Paper an endeavour will be made to show what in the Author's opinion these principles are, and to illustrate them by facts relating to one particular class of rivers.

The rivers here dealt with are those draining the Eastern Midland portion of England, and are typical of the drainage systems of flat districts of permeable strata discharging into sandy estuaries, with a small rainfall, free from mountain torrents and rapid discharges of water met with in the watersheds of volcanic districts. The industry pursued on their banks being mainly of an agricultural character, no complication arises from the pollution by manufactories.

Large sums of money have been expended on these rivers, for which some of the lands draining by them are heavily taxed. Yet owing to the piecemeal way in which this has been done, these river basins are still subject to most disastrous floods. If the same amount of money had been judiciously expended on a comprehensive plan embracing the whole river system, and the cost fairly spread over the lands benefited, these rivers would now be in a comparatively efficient state, and competent to discharge the heaviest floods without any undue burden being imposed on the land.

The Eastern Midlands lying between the Trent, the Severn and the Thames (Plate 6), are drained by four rivers, the Witham, the Welland, the Nene, and the Ouse, which discharge into the upper end of a large indent or bay on the east coast known as "The Wash." There are other small rivers draining the district lying between the watersheds of the Ouse and the Thames, which discharge at various points along the coast, but these it is not intended to deal with. The area drained by the four rivers is about 5,719 square miles; their total length about 416 miles, and with the tributaries 872 miles. The number of square miles to a mile in length of the main stream is 12·74, or 8,155 acres for the whole watershed. Including the affluents there are about 4,015 acres to a mile of river.

These rivers drain portions of the counties of Lincoln, Norfolk,

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

Northampton, Cambridge, Huntingdon, Rutland, Bedford, and Buckingham. The principal towns within the watershed are Lincoln, Boston, Grantham, Spalding, Wisbech, Peterborough, Northampton, Lynn, Cambridge, Ely, Bedford, and Dunstable. With the exception of Northampton, where shoemaking is carried on to a large extent, and Bedford and Dunstable, where the straw-plaiting industry is chiefly located, these towns are mostly agricultural centres, and are markets for the disposal of the produce grown on the lands around. The businesses carried on are almost entirely those for the supply of agricultural machinery, for the manufacture of the produce for market, or of oil cake or other food for the stock, and of artificial manures for the land. The rainfall of the district is small, ranging from 17·39 inches in the driest seasons to 34·48 inches in the wettest; the average being 26·05 inches (Appendix I.).

The country generally is flat, and the elevation at the source of the rivers is only about 300 feet above the level of the sea. The geological formation is Kimmeridge and Oxford clays, Oolites with small deposits of Lower Greensand, Chalk and Glacial drift. The lower or fen districts are alluvium and peat. The sources of the four rivers are not more than about 30 miles apart, the water producing the streams breaking out from the Oolites near the extreme north-eastern boundary of the watershed of the Severn. The lower part of the watershed, comprising about 668,241 acres, is a plain, known as "The Fens," now a tract of valuable agricultural land, but formerly a morass, which in winter, with the exception of a few elevated spots, was little better than a lake, but in summer afforded valuable pasturage for the cattle of the occupiers of the adjoining high land. After the introduction of monastic life into this country, settlements took place in the Fens by some of the religious orders. The abbots and priors began gradually to improve portions of the fen, but no systematic attempt at reclamation was made until the seventeenth century, when certain speculators or "adventurers" undertook to drain and improve the fens in return for a share of the lands. The most successful of these was the Duke of Bedford, who reclaimed a large tract of land in Cambridge and Norfolk, known as "The Bedford Level," much of which is owned by the successors of the original "adventurer."

The adventurers called to their assistance Vermuyden, a Dutch engineer, who designed his works of reclamation on a plan similar to plans adopted in Holland. Losing sight of the greater range of the tides in the estuary than on the coast of his own

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

country, he took no advantage of the gain to be obtained by discharging the drainage direct into the estuary, where low water ebbs out lower than the North sea, and thus securing a natural outfall for the water. The outfalls were neglected, embankments were made along the main rivers, and long arterial cuts through the lands to be reclaimed, with sluices at the end to keep out the tidal waters. Under this system the lower part of these river-basins became split up into a number of districts or levels, each level dealing with its own drainage irrespective of its neighbours. The aggregate amount of money thus spent in the reclamation works was far greater than it would have been had all contributed to the improvement of the common outfall. Conflicting interests were created which have since caused enormous sums to be spent in litigation, and have prevented that common action for the improvement of the rivers which is generally admitted to be necessary, and adding greatly to the difficulties of the application of any system of river conservancy.

As the original works failed to attain the purpose for which they were intended, fresh cuts were made. In many instances the course of some rivers was entirely diverted. Long straight cuts were made to supersede the winding course of some natural rivers, shortening considerably the distance the water had to travel, and accelerating their discharge. In these new rivers the flood-banks were set in some cases as much as a mile apart, the river channel occupying a space in the centre sufficient only for the ordinary discharge of water. In floods the water overflowed the ordinary banks, and spread over these "Wash lands." The country below being at that time almost entirely open marsh, the outfalls were thus capable of receiving the flood-water, and the washes being unobstructed, the floods passed rapidly away without doing any damage to the land, which was then all under grass.

The marsh lands below these washes have subsequently been reclaimed, and the outfalls otherwise choked and impeded, and the washes have long ceased to answer the purpose for which they were originally intended. Where they have not been encroached upon by being embanked from the rivers, they now in times of flood become vast lakes, which fill with water on the overflowing of the rivers, sometimes to a depth of 6 feet, the water remaining on them for several weeks together, presenting the appearance of an inland sea. The proprietors having become possessors of portions of these washes at high prices, have sought to recoup themselves by endeavouring to grow crops of hay, and in many instances by turning the fields into arable land. During

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

the last few years, owing to the continuous floods, crops have been washed away, and the land rendered of little value. The miasma arising from this land, when at length it begins to dry, after several weeks' submergence, is prejudicial to health. Thus what were intended by the engineers who designed these wash lands as flood regulators, have, by the want of a general system of control, become a nuisance.

The existence of these washes, the large area they cover, and the above facts, are sufficient answers to those theorists who are in the habit of advocating the formation of reservoirs to regulate the streams and prevent floods. Here, on rivers draining comparatively a flat country, are occasional reservoirs of 3,000 and 5,000 acres, which yet have scarcely any effect in preventing most severe floods on the lands above them. Taking an average depth of water of 4 feet over the whole of the wash lands, those on the Nene would only provide for a rainfall of 0·297 inch over the watershed draining above them, and those on the Welland of 0·48 inch.

The Witham.

The Witham rises near Thistleton and South Witham, a few miles north of Stamford, at an elevation of 339 feet above the sea. It is about 89 miles in length, has five tributaries, the Brant, the Till, the Langworth, the Bane, and the Sleaford river, their united length being about 98 miles. The area of the basin drained is 1,063 square miles, of which 196,686 acres are fen lands. The number of acres to 1 mile in length of the river and its tributaries is 3,635. The tidal flow only extends 8 miles, the tide being arrested at Boston by a sluice placed across the river, having self-acting doors, which close against the tide and open on its receding. The tide flows from two to three hours, and at spring tides there is a navigable depth at the present time of about 16 feet. Mean high water on an average of four years (1869-72) rose 18·92 feet above the Black Sluice sill at Boston, or 10·22 feet above ordnance datum; spring tides, 22·02 feet; neaps, 15·36 feet. A spring tide which rose 23 feet 4 inches in Clayhole, rose 13 feet 2 inches at Boston; and a neap tide, which ranged 9 feet 2 inches in Clayhole, ranged 6 feet at Boston. By the works now being carried on under the Witham Outfall Act of 1880, it is expected to give a navigable depth of 22 feet at the proposed entrance to the new docks at Boston.

Between Boston and the lock at Bardney, a distance of 20 miles, water is maintained for purposes of navigation at a uniform

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

depth of 9 feet. The Commissioners have now, under the Act of 1881, obtained power to reduce this when necessary. In floods the regulating doors at the Grand Sluice at Boston are withdrawn, and the water allowed to flow without interruption. The sluice has four openings of 16 feet each, and the depth of water on the sill at ordinary floods is about 10 feet, rising as high as 14 feet in extreme floods. The fall in the surface of the water in floods between Bardney and Boston is from 3 to 5 inches per mile, and between Boston and the sea 25 inches per mile. The waterway of the river about 2 miles below Boston is 200 feet at low water. With 10 feet of water the area is 2,000 square feet. The area drained through this part of the channel is 650,392 acres, thus giving 325 acres to every square foot of waterway. The waterway of the Grand Sluice is 66 feet, and with a depth of 10 feet on the sill it has an area of 660 feet. The river above was originally excavated so as to give a mean waterway corresponding with that of the sluice. The number of acres draining through the sluice is about 448,835, being 680 acres to a square foot. The area of the river at Boston at ordinary low water is 156 square feet, and at high water of spring tides 2,286 square feet, a proportion of 1 to 14·6. But in comparing this with the other rivers, it must be borne in mind that the section is taken only 7 miles from the estuary, the tidal flow being arrested at the Grand Sluice, 1 mile further up the river.

The river has been considerably altered below the City of Lincoln, from which place it is mostly artificial. About the middle of the last century the banks on both sides of the river from Boston to Lincoln were raised and strengthened, the greatest of the bends removed by new straight cuts, and the channel generally deepened, widened, and improved. The Grand Sluice was erected for preventing the tide flowing into the upper reach of the river. These works were completed in 1766, at a cost of about £53,650. In 1811 a further amount of £30,000 was spent on this portion of the river. Additional works have been carried out under an Act obtained in 1865, for deepening and removing obstructions from the channel, and strengthening and raising the banks. The cost was about £50,000. The navigation authorities have expended, during the last fifty years, about £60,000 in straightening and training the tidal portion of the river below Boston. Under an Act obtained in 1880, works are now being carried out for making a new outfall by a cut 2½ miles in length, by which the distance will be shortened 1½ mile, and the shifting sands at the mouth of the river avoided. It is expected that this

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

will give a relief of at least 3 feet in the low-water mark at the drainage sluices.

The cost of the works executed up to the present time is upwards of £300,000, and the works for the outfall are estimated to cost £120,000 more. Beyond this a large sum has been spent on works for improving the river by the owners of the upper navigation. The cost has been met by taxes on the low lands and by dues on the shipping. The taxes on the fen lands for river works vary from 1*s.* to 5*s.* 6*d.* an acre, in addition to what has to be paid for works of interior improvement, which on some of the fens brings the amount of drainage taxation up to 16*s.* per acre. This amount extends over a length of 35 miles of the lower part of the river, or only about one half of its course. Further expense has been incurred in straightening and improving the upper reaches, by which the water is discharged more rapidly into the lower part, but the landowners contribute nothing to the works below Lincoln. Notwithstanding the improvements, the river is incapable of discharging the water as quickly as it is poured into it, owing to the defective outfall at the sea, to the obstruction caused by the sluice at Boston, the weirs at Lincoln, and the inadequacy of the channel between those places, and consequently the floods on this river have been increasingly frequent and disastrous. The lower part of the city of Lincoln has been several times under water, the houses for a time being rendered uninhabitable and the large engineering works stopped. In the winter of 1876, when several of the interior banks were broken, 40,000 acres of land were under water, people were driven from their houses, and cropping was lost to the estimated value of £100,000. In 1878 and 1879 there were very heavy floods; and in the autumn of 1880 a large tract of land was again submerged; the corn stacks were standing several feet in water, and sheaves of corn which had not been carried away were floating about in the fields. Not only were the farmers injured, but much valuable food was destroyed.

The Welland.

The Welland rises in a gentle range of hills between Lutterworth and Market Harborough, near the source of the Ise, a tributary of the Nene. It is about 72 miles long, has three tributaries, together 65 miles long, and drains about 707 square miles, of which 76,854 acres are fen land. The number of acres to 1 mile in length of the river and its principal tributaries is 3,302.

The Welland has a tidal course of 20 miles; extreme tides reach

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

as far as Crowland. A spring tide which rose 23 feet 4 inches at Clayhole rose 12 feet 2 inches at Fosdyke bridge, 8 miles from the estuary, and 4 feet at Spalding, 15 miles from the estuary. When the river is thoroughly scoured out to its full depth the rise at spring tides is 8 feet, giving 10 feet at high water of spring tides. The range of a neap tide, which was 9 feet 2 inches at Clayhole, was 5 feet 5 inches at Fosdyke, but the tide did not reach Spalding.

The mean inclination of the surface of the water between Spalding and Clayhole at ordinary low water is 14 inches per mile. During floods, in the trained portion of the channel below Fosdyke bridge, the inclination is 9 inches per mile, and between Fosdyke and Spalding 2 feet per mile. In large floods the average inclination from Spalding to low water of spring tides in the estuary, 15 miles, is 21 inches per mile. Owing to the want of prolongation of the trained channel, the fall from Fosdyke bridge to low water in Clayhole, 8 miles, averages about 18 inches per mile, due to the great fall between the end of the trained work and Clayhole.

The average waterway of the river at Spalding is about 40 feet, and the area in floods 400 square feet. The drainage area discharging there 300,000 acres, giving 750 acres to a square foot. The mean width of the trained channel below Fosdyke is 120 feet; the area of the waterway with 10 feet depth of water is 1,200 square feet. The drainage area discharging through this channel is about 452,480 acres, or 377 acres to a square foot.

The area at Spalding at low water is about 73 square feet, and at high water spring tides 485 square feet, a proportion of 6·65 to 1.

The Welland retains its ancient course more nearly than any of the other rivers, yet it has been considerably altered. The river was made navigable from Stamford to the sea by improvements in the channel of the river, straightening the same by new cuts, and by the erection of locks, &c., the first lock on the river being about 13 miles above Spalding. Subsequently the adventurers of Deeping fen, in order to obtain a better outfall for their drainage, widened and deepened the river below Spalding. In the year 1801 a new cut was made from the reservoir 8 miles below Spalding, and the open marshes above Fosdyke were enclosed. About forty-five years ago the work of training the river by fascine work through the shifting sands below Fosdyke bridge was commenced and continued for a length of 3 miles 30 chains. This training had the effect of lowering the low-water level at Fosdyke bridge 7 feet. The whole of these works, so far as they relate to the improvement of the river as the outfall of the drainage of the country, were paid for by the Fen land in the

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

low level of the river basin, assisted by dues levied on the shipping using the artificial channels.

The arterial drainage of this district is still in a very defective condition, the channel not being sufficiently adapted to carry off the rainfall as rapidly as it is collected in the river. The banks which protect the fens are constantly being broken, owing to the channel being overfull and the fens flooded. The repeated floods of the last few years have done an immense amount of damage by submerging the land and destroying the crops. In July, 1880, in addition to thousands of acres of land which were submerged, the whole of the lower part of the town of Stamford was flooded, as were also the villages of Market Deeping, Elton, Maxey, and others on the course of the river, the water rising to a height of 3 and 4 feet in some of the houses. Again, in the autumn of the same year, a flood, almost as extensive and if anything more disastrous in its results, occurred. Although floods so calamitous are exceptional, yet their frequency and the large area of land thrown out of cultivation, are sufficient to demand that such alterations should be made in the river, as the main outfall of the drainage of the district, as to render it efficient for its purpose.

The Nene.

The Nene rises in two springs at Daventry, and owing to its windings, although in a direct course the distance is only 60 miles, the length of the river is 99 miles. It has three tributaries; the Ise, the Harper, and Willow Brook, their united length being 52 miles.

The Nene has a drainage area of about 1,055 square miles. The number of acres to 1 mile in length of the river and its tributaries is 4,474.

The tidal flow is 34 miles, at spring tides, reaching Northey Gravel within $2\frac{3}{4}$ miles of Peterborough, and at extreme tides even as far as Peterborough. The tide flows three and a half hours at Sutton bridge, 7 miles from the estuary, and two and three quarter hours at Wisbech, 15 miles from the estuary. A spring tide, which rose 23 feet 3 inches in the estuary, rose 20 feet 6 inches at Sutton bridge, and 15 feet 2 inches at Wisbech. A neap tide, of which the range was 9 feet 1 inch in the estuary, ranged 8 feet 5 inches at Wisbech. The navigable depth of water at Wisbech is about 22 feet at high water spring tides, and 3 feet at low water. From observations made by Sir John Coode, M. Inst. C.E., it appears that, owing to the tide being throttled by the contracted form of the lower part of the channel, it has not

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

free ingress and egress, and does not reach the limit of its flow until some time after the ebb has commenced at the lower end. Thus the particular tide observed ebbed three and a quarter hours at the lower end of the trained portion of the channel before it had reached the "Dog in a Doublet," 25 miles above, and then continued flowing there for forty-five minutes. The water rose 6 feet at the upper end, while it fell 6 feet 11 inches at the lower end. Thus there are two strong currents in the river running simultaneously in opposite directions, the ebb towards the sea and the flow towards Peterborough. High water spring tides is 7 feet lower at Peterborough than at the outfall at Stone Ends, and at neap tides it is 8 inches lower at Cross Guns, 24 miles from the outfall.

The mean inclination of the surface of the water at low water from Peterborough to the sea is at the rate of 5·63 inches per mile. This rate varies considerably along the different sections, the minimum being 2 inches per mile along the lower reach, and the maximum at the Horse Shoe bend at Wisbech 14½ inches per mile. In severe floods the inclination from the South Holland sluice above Sutton bridge to low water at spring tides in the estuary, 8¼ miles, is at the rate of 10½ inches per mile. Through Wisbech, in great floods, there is a fall of 3 feet in less than a mile.

The mean waterway of the river in the upper reach, a short distance above Wisbech, is 50 feet, giving an area with 10 feet depth of water of 500 square feet. The area of land draining through this part of the river is about 564,700 acres, or 1,129½ acres to a square foot. In the lower reach, between the stone banks of the trained channel, the waterway is about 220 feet, and with a depth of 10 feet the river has an area of 2,200 square feet. The area of land drained is about 675,200 acres, being 307 acres to a foot. Taking the area above Wisbech at ordinary low water at 240 square feet, and at high water of spring tides 1,595 square feet, the proportion of tidal to fresh water for the ordinary flow is 6·65 to 1.

The Nene is navigable from Northampton; it enters the fens at Peterborough, and then divides into two branches, one branch, the old river, joins the Ouse by a branch from Stanground sluice. The main stream runs by Smith's Leam through the wash lands and Wisbech to the sea. The Nene has been more altered by various works than any other river. From Peterborough to the sea it is nearly a new river. Bishop Morton in 1478–86 first commenced the alterations, diverting the river from its original course by a new cut from Peterborough to

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

the water 7 miles. In 1726 the present channel of the river between Peterborough and Guyhirne was made, its course being parallel with Morton's Leam. The banks are about ½ mile apart, leaving 3,500 acres of low-lying meadow land or "washes." At Guyhirne, 6 miles above Wisbech, these banks come together and are close upon the river. From the Horse Shoe bend towards the sea below Wisbech a channel was cut by King Charles. In 1773 a new cut was made 1½ mile in length 5 miles from Wisbech, since known as "Kinderley cut;" and between 1827 and 1832 this was continued by the Woodhouse, or "Pauper's cut," so called from a number of paupers having been employed on the works. About fifty years ago the improvement of the river below these cuts was continued by excavating and scouring a new channel through the Cross Key washes from Gunthorpe sluice to Crab's Hole, a distance of 5 miles, with further training banks through the sands about 1¼ mile in length. A large tract of land was at the same time reclaimed. The new outfall lowered the low water at the North-Level sluice 10 feet. In 1813, before the last improvement was made, the fall in the surface of the river was at the rate of 3 feet per mile. Afterwards it was only 3 inches in the mile. In 1852 further powers were obtained for improving the river between Peterborough and the sea, and after an expenditure of £200,000 the works were discontinued without any material improvement having been effected. The alteration in the channel of the river greatly augmented the range of the tides. In 1769, according to a report of Golborne,[1] spring tides only rose 4 feet at Wisbech, and neap tides did not reach the town; after the new channel was made they rose from 15 to 16 feet.

Within the last century the amount spent on the improvement of the main channel of the Nene has been upwards of £450,000, about one-fourth of which sum was raised on the navigation dues, to meet which all ships entering the port are subject to a charge of 1*s.* 0½*d.* per ton-register, and the remainder by the fen land. The taxes on the land to meet this outlay reach in some cases 15*s.* an acre, and yet the land is occasionally flooded. The river is in a most unsatisfactory condition, thousands of acres of land along the valley being sometimes inundated, and even the streets of Peterborough flooded and people driven from their houses, while the whole arterial drainage system suffers from its defective condition.

---

[1] *Vide* The Report of John Golborne, Engineer, concerning the drainage of the North Level of the Fens, and the outfall of the Wisbeach River. [Inst. C.E. Tracts. 4to. Vol. liv.]

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

The Ouse.

The Ouse rises at an elevation of 300 feet above the sea in numerous springs; these escape from the Oolite escarpment at its junction with the Lias Clay above the valley of the Cherwell, between the Ouse and the Thames, and within 4 miles of one of the sources of the Nene. The head of the main branch is about 87 miles from the sea, but owing to the tortuous course of the river the length of the channel is 156 miles. It has ten tributaries, their united length being 241 miles. The drainage area is 2,894 square miles. The number of acres to 1 mile in length of river and tributaries is 4,672. The river for the last 50 miles of its course runs through a flat low-lying district, and has been embanked from St. Ives downwards. Spring tides flow a considerable distance up the Hundred-Foot river, or nearly to Earith, 20 miles beyond Denver sluice, giving a tidal course of 40 miles.

The average rise of a spring tide at the Free bridge above Lynn, as taken from the records observed there over a period of seven years (1869–75) was 18·51 feet above zero, which is about 1·31 foot above low water of spring tides. The highest tide observed during that period was 22 feet 6 inches, an average neap tide was 12·04 feet, and the mean of all tides 15·54 feet, or 10·59 feet above ordnance datum. A spring tide, which rose 23 feet 3 inches above low water in Lynn Roads, rose 22 feet 6 inches at Lynn; and a neap tide, which ranged 9 feet 1 inch in the estuary, ranged 9 feet 5 inches at Lynn. The tide flows for about five hours at Lynn.

The ordinary low-water inclination of the surface of the water along the Eau Brink cut is about 3 inches per mile. In large floods the mean inclination from Denver sluice to low water in the estuary, a distance of 19 miles, is at the rate of 9 inches per mile. From Denver to Lynn the surface inclination is 12 inches, and from Lynn to the estuary 8 inches.

The area of the waterway of the river above Earith is very irregular. That of the channel near Earith is only 243 square feet, while 7 miles further up, the river, near St. Ives, has a sectional area of 672 square feet. At Over Court Ferry the area is 492 square feet. The area of the outlets for flood-water above Earith was found by Mr. Abernethy, President Inst. C.E., in 1875 to be 4,233 square feet, while below the Seven-hole sluice at Earith it was only 2,058 square feet. The shuttles at the Seven-hole sluice are not lifted till the flood-waters have risen 4 feet 6 inches above the level of the wash lands, or until a large part of

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

Wisbech, about 11 miles in length, which shortened the course of the country, is flooded. The fall in floods from the upper to the lower side of this sluice is 2 feet, caused by its restricted size as an outlet for the large area which has to drain through the sluice. In the Eau Brink cut the area in floods is about 2,620 square feet; and the drainage area being 1,852,160 acres, gives about 707 acres to a foot. In the Marsh cut the dimensions of the cut, originally set out with slopes 4 to 1, have increased by the washing away of the banks from 265 feet at the bottom to an average of 425 feet, and from 500 feet at the top to an average of 594 feet. The depth originally was 10 feet 4 inches, and now varies from 10 feet to 19 feet, averaging 12 feet 8 inches. The channel below the Marsh cut, where it is confined by guide-walls of stones and fascines, is 400 feet wide, and, taking the depth at 19 feet, gives 463 acres to a foot of sectional area of waterway.

The section of the Eau Brink cut has also become very irregular since its first formation. From a number of measurements in 1862 it was found that the sectional area at low water in some places was double that in others, and the depth at low water varied from 17 feet 3 inches to 2 feet 9 inches. The mean of forty-three measurements gave the area at ordinary low water as 1,824 square feet, and at high water of spring tides 9,421 square feet, a proportion of 5·16 to 1.

The average low-water level of ten years, 1844–53, previous to the completion of the Marsh Cut, was 2 feet 5½ inches above the datum at the Free bridge, and for ten years after the opening of the cut, 1866–75, 9¼ inches below, showing an average gain of 3 feet 2¾ inches. The extreme low water varies from 3 feet 6 inches above datum to 3 feet 6 inches below, or a range of 7 feet. The average low-water level of spring tides at the Free bridge is now about 1 foot 3¾ inches below datum, or 3 feet 8 inches above low-water spring tides in the estuary; and during neap tides 2¾ inches above datum, or 5 feet 3 inches above low water.

The Ouse stands first of all the Fen rivers in the large amount of money which has been expended in its improvement. Without taking account of what was done by the early adventurers, upwards of £800,000 have been raised and expended in making new cuts, and otherwise improving that portion of the river which passes through the Fen land. The benefit of these improvements has been enormous, the low-water level having been depressed 12 feet.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

Vermuyden began the alterations in this river in 1638 by making a new cut 21 miles long and 70 feet wide, called the Old Bedford river, from Earith, where the river enters the fen jurisdiction, to Denver sluice. In 1652 the New Bedford, or Hundred-Foot river, was made parallel with the other; and banks were raised on the north side of the old Bedford river and the south side of the new river, leaving an area of 5,000 acres of wash lands between. By this cut the course of the river was shortened 10 miles; and the old course of the river being maintained, there were three channels for the river. In 1748 Denver sluice was erected, by which the tidal flow was stopped from going up the old river course, but was still allowed a free run up the Hundred-Foot river. Subsequently the Hermitage, or Seven-hole sluice, was erected at Earith, and all the water coming from the basin of the Ouse above this, extending to 756,000 acres, was discharged by the new river, while the old Bedford river and the wash lands afforded receptacles for the waters in extreme floods. By an Act passed in 1812 the owners were allowed partly to embank the washes, and they have since been gradually encroached upon, their use as flood-regulators being otherwise destroyed.

The Eau Brink cut was originally projected by Kinderley in 1720, and the Act was obtained in 1795; but it was not completed until 1821. The original estimate was £39,985; the ultimate cost, £600,000. The length of the cut is 2½ miles, the old course of the river being 5 miles. The effect of the cut was to lower the low water 6 feet at Denver sluice, and 8 to 9 feet at Eau Brink, where the new cut joined the old river. In 1853 the Norfolk Estuary Company made a new cut through the marshes below Lynn 2 miles in length, and continued the channel by training through the Vinegar middle sands for a distance of about a mile. The cost of this work was upwards of £200,000, towards which the drainage and the navigation contributed £110,000. This cut shortened the course of the river, and depressed the low-water level 3 feet at Lynn. Since the opening of the Marsh cut the river has been further improved by dredging away a large clay bar or shoal lying between the Eau Brink cut and the Marsh cut.

Inland Navigation.

The present condition of the inland navigation seriously affects these rivers, and is one chief cause of their incapacity for carrying away flood-waters. Owing to the position of the Wash with reference to the Netherlands and the Continent, Lynn and Boston

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

were once prominent ports, ranking only second to London and Bristol; and although a great portion of this trade was diverted by the opening up of Hull and other ports on the east coast, yet up to the time of the construction of railways there was a large export trade of wheat and agricultural products, and an import of coals and other goods which were distributed throughout the midland part of England by these rivers. Water carriage was almost the only means of conveying heavy products into the country, and of exporting the corn and wool; as this traffic increased, the rivers, where they became shallow, were canalised and made navigable by locks or staunches. Thus Bedford by the Ouse, Northampton by the Nene, Stamford by the Welland, and Lincoln by the Witham, with other smaller towns, were placed in communication with the sea.

So long as these navigations were maintained in order, the shoals cleaned out as they accumulated, the locks and staunches preserved in efficient condition, and the weeds cut or kept down by the traffic of the boats, the rivers even in their artificial state of canalisation were capable of discharging the flood-waters; but since railways have diverted the traffic from these inland rivers, navigation has ceased, the works have gone to ruin for want of funds to maintain them, and shoals and weeds choke the channels. The rivers have become in a far worse condition to discharge the drainage of the country than when left in their natural state, and constant floods are the consequence. The proprietors of the navigations, who have suffered greatly by the loss of the dues, although unable to fulfil the duties belonging to a proper maintenance of the streams, still cling to the remnant of traffic left. For this they adhere to their rights as to the holding up of the water, without having the means to adapt the rivers to the modern requirement of drainage by enlarging the capacity of the weirs, so as in times of flood to discharge waters sent down at a much greater rate than formerly.

On the Witham, for a distance of 30 miles between Boston and Lincoln, the river is practically a canal. The tide is stopped by a sluice at Boston, and a weir and locks had to be constructed at Bardney and Lincoln. The inland water is held up to a constant height on the sill of this sluice by penstocks, for the purposes of the navigation. The navigation having been taken over by the Great Northern Railway Company, the works are maintained in efficient condition, but the obligation imposed by the original Act of holding up the water seriously affects the drainage. The river Slea, from Sleaford to the Witham, was made into a canal in 1792.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

The navigation on this river having almost entirely ceased, the company was dissolved by an Act recently obtained. The Bane, another affluent of the Witham, was also canalised, forming a navigation from the Witham to the town of Horncastle; but the dues obtained are insufficient to maintain the works in proper order.

On the Nene, which is canalised from Peterborough to Northampton, the navigation is reduced to a few barges. The constant floods on this river are ascribed in a great measure to the defective condition of the works. The proprietors of the navigation, on whom was cast the duty of maintaining the river, no longer have the funds, and there is nobody to take their place. The same thing has occurred on the Ouse between Earith and Bedford.

On some of the affluents of these rivers, which under legislative powers granted last century had been converted into "navigations," the proprietors have obtained Acts of Parliament relieving them of their rights and liabilities, and there is now no jurisdiction over these rivers, or anybody responsible for removing shoals or cutting weeds. The beds of these streams have consequently grown shallow, and the rivers are no longer capable of acting as efficient arterial drains. Thus on the Ivel, an affluent of the Ouse, the navigation trust created in the reign of George II., was abolished in 1876. The river is said to have since diminished one-half in width and one-half in depth, and the bottom is being gradually raised above the level of the land. In like manner the Lark, another canalised affluent, has almost entirely silted up since the navigation of the river ceased. The Ouse itself above Earith is obstructed by numerous shoals, and an enormous growth of weeds. These were originally kept down by the constant passage of the vessels, and the shoals were removed by the trustees of the navigation.

It is no doubt a great advantage to the water supply, and also for the water power of the country through which these rivers pass, and conducive to the economical conveyance of gravel, stone, lime, manures, and other heavy materials, where time is of no great consequence, that the locks, weirs, and works should not be abandoned, and the rivers restored to their natural state; but it is desirable that these works should be placed under a jurisdiction interested in and having control over the drainage, and that by the enlargement and improvement of the weirs and other works the rivers should be placed in a state of efficiency.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

Cause of Floods.

From the improved system of drainage now pursued, necessitated by the higher cultivation of the land, the rain is more rapidly discharged into the rivers. The water is no longer suffered to fill the land like a sponge, and pass off either by evaporation or slow percolation through the subsoil, but rapidly soaks through the soil broken up and disintegrated by steam ploughing and deep cultivation, and as soon as the sub-stratum is saturated to the level of the drain-pipes, the rain-water is carried to the ditches. Efficient pipe drainage necessitates clean ditches, and the straightening and improving of all arterial drains and minor watercourses. Thus every impediment is removed from the free flow of the water to the river. Large tracts of water known as meres, which formerly acted as reservoirs, have been drained; woods and plantations which absorbed and held the rainfall have been stubbed up. Villages and towns are drained, and everywhere, whether in town or country, every effort is made to prevent stagnation, and speedily to void the water. An increase in the rainfall has also no doubt contributed to the increase of floods. On examining the statistics of rainfall kept at Boston for the past fifty years, it appears that there has been a considerable increase in the annual rainfall during the last few years, and especially during the last five. The average annual rainfall of the last five years has been 29·04 inches, or a greater quantity than previously recorded during a like period, and 5·62 inches above the average of the last fifty years. The next wettest period was 1846-50, when the average annual fall was 4·22 inches less than during the last five years. Taking ten-year periods, the average annual rainfall of the last ten years has been 4·34 inches greater than of the previous ten years, and 4·78 inches more than the ten years 1851-60, and 1·83 inch over 1841-50. Taking twenty-year periods, the last twenty years is 1·14 inch in excess of the previous twenty years and 4·11 inches in excess of the previous fourteen years. The largest increase has been in the months of September, February, and December, and the least in July and October. During the last few years September has had the greatest fall, and March the least (Appendix II.)

Meantime no provision has been made to meet this more rapid discharge. In the upper reaches of the rivers no adequate jurisdiction exists to prevent obstructions, to compel the maintenance of works, or to levy taxes for carrying out improvements. In the lower reaches the works have been done in sections, and without reference to the general drainage-system of the rivers,

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

and have been for the benefit of, and are paid by, the low lands, the owners of which of course are opposed to any improvements which will bring the upland waters on to them more rapidly. In fact, so jealous are the managers of the lower reaches of the river, that powers have been obtained enabling them to regulate the quantity arriving from the upper reaches. On the Ouse at Earith a sluice regulates the flow of water from above, in which the openings are not only too contracted to allow the flood-waters to pass freely through, but the shuttles are not lifted until the water has risen to more than flood-height on the lands above. In the Witham, at Lincoln, the quantity of the discharge is regulated by a weir, which is inadequate in times of flood, but any increase in the size of which is prevented by the Commissioners having the control of the drainage below, the consequence being that the lower part of the city and upwards of 15,000 acres of land above this weir are frequently flooded.

The openings of the bridges across the rivers, most of which were built before the conditions of drainage were altered, are many of them totally inadequate to the discharge of the waters, and great discrepancies exist in the area of the waterways. Thus Mr. Abernethy states in his report on the Ouse that the bridges over the Hundred-Foot river have only half the area of the waterway of those at St. Ives 12 or 13 miles higher up.

The growth of weeds, and the increase in the cesses or banks of the rivers which have gradually encroached on the waterway, form another serious and increasing obstruction. Owing to the careless way in which the weeds are cut in some of the rivers, they are allowed to float down the stream, settling in the shallow places where sand and alluvium collect, in time forming large shoals, and even islands, in the centre of the streams.

Where watermills exist there is no jurisdiction to compel the miller to maintain his works and regulate the weirs so as to give sufficient waterway in times of flood. Water-power is too valuable to be done away with, and the holding up of the water is a great advantage to the locality; but the owner should be placed under such restrictions that his weir and by-passes should be of sufficient capacity, and he should not be allowed to interfere with the efficient discharge of the water during floods.

In like manner the weirs belonging to the navigation need remodelling, and the works to be placed under an efficient system of supervision along the whole river.

The effect of the floods of recent years has been most disastrous to the owners and occupiers of land from the losses they have

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

incurred, and to the nation generally from the immense amount of produce destroyed. Thousands of acres of corn have been ruined by the summer floods, and land has been put out of cultivation by floods in the winter. The hay crops have been floated off the meadows and carried down the rivers, and a large area of rich pasture land has been so long inundated that the herbage has been rendered valueless. Additional taxes have also to be levied to pay for breaches in the river and drain banks caused by the floods, and for the maintenance of steam-power to pump the water off the flooded lands. It is not easy to calculate the loss which has been incurred during the last few years, but it certainly very far exceeds any sum required to place these rivers in a satisfactory condition.

Remedy.

The works necessary for the prevention of floods in these rivers require to be carried out on a comprehensive scheme, commencing with the outfall and working upwards throughout the whole length of the channel.

The four rivers here specially referred to, discharging into the head of a bay or estuary abounding in shifting sands, are liable to have their mouths choked. The conflict between the ebb current and the flood invariably has a tendency to throw up a bar at the point where the confined channel debouches into the open. All works of improvement in the way of training and confining the channels ought therefore to be progressive and continuous, gradually pushing the confined channel forward to deep water.

In carrying out these training works the walls require to be at such a height and width as to prevent any retardation or choking of the tidal flow. The object to be sought is to give a free action to the tidal current as the principal agent in maintaining these channels in their most efficient condition, and to ensure that the last of the ebb shall be directed along a definite channel, so as to take every advantage of its scouring power. For this purpose the width of the channel should decrease from the sea gradually, and the training walls, commencing at the lower end with a height equal to low water of neap tides, should, as they advance, reach to that of half-tide level.

Already the outfalls of the Nene and of the Ouse, which had been trained to deep water, are encumbered with sand. In the Nene the depth of water at the end of the trained channel has gradually decreased from 9 feet to 2 feet, the depth in the trained portion being 8 feet. Across the outfall of the Ouse there is a sand-bar,

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

with only a depth of water 5 feet against 9 feet in the trained channel. In both cases the training requires to be carried seaward slowly, but continuously, or the advantages gained will disappear. The Welland discharges into a sand bed 4 miles distant from deep water; in fact, it may be said that when the water leaves the fascine work it no longer has any defined channel, but meanders over the sands, continually shifting its course. The Witham is in the same condition, but works are now being executed to carry the channel to deep water.

Notwithstanding the bars forming at the mouths of the Nene and the Ouse, the advantage of the improvements already effected in the outfalls of those channels is shown by a comparison of the level of low water in floods with that of the Witham. Taking each river at a point 8 miles from the estuary, the average level of low water of the same flood over a period of seven days was 16 feet 6 inches above low water of spring tides in the estuary in the Witham; in the Nene 7 feet 7 inches above, and in the Ouse 5 feet 6 inches above; showing a difference of 11 feet in the low-water level between the Ouse and the Witham.

The Author has not been able to collect sufficient data to form any definite opinion as to the result of the works carried out in these rivers in raising or lowering the level of high water; but by a comparison of four years' tides at Lynn and Boston, it appears that mean high water is about 4 inches higher at Lynn than at Boston, which would show that the proper regulation of the channel has not a tendency to lower the high-water mark.

The value of tidal waters in maintaining the channels of these rivers in an efficient condition is of the utmost importance; and the deductions drawn from observations lead the Author to an opposite conclusion to that laid down in the Paper by Mr. W. R. Browne, M. Inst. C.E., on the relative value of tidal and upland waters in maintaining rivers, estuaries, and harbours.[1] It is not contended that the enclosure of the marshes reclaimed by the training works has had any material influence on the outfall, the silting up of which is, as already explained, due to other causes, and would equally have taken place had these marshes remained open; but for the maintenance of the channel a free flow and ebb of the tidal water up and down the river is essential to prevent the sand carried up with the tide from being deposited. So long as the water is in motion only a small portion of the sand which is held in suspension settles; but where there is an obstruction to

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxvi., p. 1.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

the tidal flow, and the water remains quiet, the heavy particles at once begin to sink and accumulate. In summer, when the flow of fresh water is small, this deposit remains. The quantity of water at spring tides in the embanked channels of these rivers is ordinarily six times as great as the upland water, and, being always in motion, must therefore have a greater effect in maintaining the channels of the rivers. The Ouse is in the best con dition to allow a free run of tidal water; the Witham the worst. In the former river the tidal flow is 40 miles, and, even in the driest season, scarcely any silting up of the reaches of the channel occurs. In the latter the tidal flow is only 7 miles, the tide being stopped by a sluice; the deposits have been so great in dry seasons as to raise the bed of the river upwards of 11 feet at the upper end, and an average of 8 feet over the whole length of the trained portion of the channel, leaving upwards of 1,500,000 tons of silt and sand to be washed out by the winter floods, which have had to rise nearly high enough to submerge the country before they could flow over the deposit. In the Welland, which has a smaller drainage area, but a tidal flow of 20 miles, during the same season the depth of the deposit left at the head of the tides did not amount to more than 2 feet 6 inches.

Following the improvement of the outfall, the channel requires regulating throughout its whole length by widening and deepening in parts and confining the low-water level where too wide so as to give a general uniformity throughout. Too great a width impedes the free discharge almost as much as where the channel is too restricted. By the diminution in the velocity of the current owing to the greater capacity, deposits take place and shoals are formed through which the water continually alters its course as the ebb or the flood current is the stronger. In the Marsh cut of the Ouse the banks have been gradually washed away, and the channel has become considerably wider than in the trained portion below; consequently shoals are forming, and the section of the channel has become very irregular, causing disturbance and increased friction and restricting the area of discharge.

Where the water is held up in the upper reaches, the weirs should be adapted to the largest flood discharge, as should all bridges and other structures across the waterway. While sufficient waterway should be secured for all floods, the low-water channel should be so restricted as to maintain its scouring power in the fullest efficiency. It is in the adaptation of the channel to the normal flow, and also to the flood discharge, that the greatest difficulty occurs. The proportion between the one and the other, even in

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

the flat district of the river basins here dealt with, may be taken as 10 to 1. Extreme floods occur only at uncertain and distant intervals. During the last thirty years there have been only twelve floods in this district which have done any serious amount of damage, a list of which will be found in Appendix II. Therefore if the channels be made sufficiently capacious to carry off these, they would be far too large for the ordinary discharge, and would become choked with shoals and weeds. The great expense and waste of land which would result from a channel made sufficiently capacious to carry off excessive floods, at once show that any such idea is impracticable.

In river improvement it must always be a matter of consideration whether the advantage to be gained by any particular scheme will be equal to the outlay, and whether it be not better to allow tracts of low-lying land, which are now occasionally flooded, to remain so, than to spend more than the value of their fee simple in protecting them. As pasture land they would always have a certain value, and where the owners have broken up such tracts into arable land, they have done so knowing the risk, and should abide by it.

A careful investigation into the rainfall in the Witham basin of the last fourteen years tends to the conclusion that the height of the floods is not entirely due to the actual amount of rain falling, as much depends on the condition of the land and other circumstances prevailing at the time. Taking the rainfall of Boston as typical of that of the Witham and Welland basins, a fall of $2\frac{1}{2}$ inches in three days in July 1867, only raised the water in the main drains 3 inches, whereas the same quantity, in July 1872, made very heavy freshets in the river, and in July 1880 caused a serious flood. Again, in 1868, although the rainfall for the autumn was heavy and continuous, and 6 inches above the average, yet the water in the Witham had not risen to flood height until the end of December. On the other hand, a fall of 1·66 inch of rain and snow in January 1867 rapidly filled the rivers and flooded a considerable area of Fen lands, although the rainfall for the previous period had not been excessive.

It has generally been the custom in designing fen drainage to allow at the rate of a continuous fall of 0·25 inch of rain during twenty-four hours. This calculation was adopted by Sir John Hawkshaw, Past-President Inst. C.E., in his report for the discharge of the whole basin of the Witham, and also for the large pumping engines at Lade Bank, for draining the East Fen. Sir John Coode, in his scheme for the improvement of the North

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

Level drainage in the Nene, provided for 0·25 inch, although he considered 0·187 inch would be all that would come daily to the outfall. During floods he ascertained that a quantity equal to 0·10 inch over the whole area of 79,855 acres was daily discharged.

During the last few years (Appendix I.), the rainfall in the Witham district, if taken over seven days, would give a daily mean of 0·37 inch, or if over fourteen days, 0·25 inch, the maximum for the seven-day period being 0·63 inch, and for the fourteen days, 0·34 inch. Although at such times the ground is fully saturated, and in an exceptional condition, it is not possible that the whole of the rain which falls could be delivered at the outfall. The mean discharging capacity of the four rivers is equal to 0·094 inch every twenty-four hours, allowing a velocity of 3 feet per second (about 2 miles an hour).

To adapt the channel to the discharge of 0·25 inch in twenty-four hours would therefore require that they should be made nearly three times their present size, a course which, even if practicable, would render them far too large for all ordinary discharges. Provision for a continuous discharge of 0·25 inch of rain every twenty-four hours would require, with a velocity in the channel of 3 feet per second, a sectional area equal to 1 square foot for every 285 acres, whereas at the present time there is only an average of 1 square foot to every 816·6 acres (Appendix IV.)

The present discharging capacity of the Witham is equal to 0·105 inch of rain in twenty-four hours; of the Welland, 0·096 inch; of the Nene, 0·063 inch; and of the Ouse, 0·101 inch; and this is not sufficient to prevent flooding.

It becomes, then, necessary first to provide a channel for the ordinary discharge of the river, and also for occasional excessive floods. A modification of the system of wash lands, already referred to, points to the method of securing this end. The ordinary channel of a river should be of sufficient capacity to take the normal flow of the stream, the sides being made at as steep a batter as the natural inclination of the soil would allow, and at such a height as may be desirable for retaining the water for the supply of agricultural and domestic purposes or water-power. The water being then retained in as small a compass as possible, the weeds would be less likely to grow and shoals to accumulate. The sides beyond this should be laid at a slope sufficiently flat to allow of the growth of grass and the feeding of sheep and cattle in summer, and the protecting banks set sufficiently far back to allow room for the passage of the greatest floods likely to occur. Where banks already exist, they would require removing on one side at least, and where there

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

are no banks the material dredged and cleaned out of the channel would in many cases be sufficient to form them. Bridges and other openings must of course be adapted to the flood discharge. By this means provision would be secured for both ordinary and flood-water, without loss of productive land, and the varying character of the discharge accommodated.

Where the channel passes through a town, as the Witham at Boston, the Welland at Spalding, and the Nene at Wisbech, the difficulty of altering the river is no doubt greatly enhanced; but it may be overcome in the manner proposed by Mr. Abernethy for Wisbech, by making an entirely new cut for the river, and dockising that portion of the old river which passed through the town. By this means the discharge of the floods would be provided for, and by removing the ships from the channel where they are always an obstruction in floods, they would be enabled to lie and discharge afloat in the dockised channel of the old river at the existing granaries and warehouses.

It may no doubt be urged that the expense of thus altering and adapting a river to meet ordinary flood discharges would be very great, but if the cost was equitably spread over the whole watershed, the tax would not be greater than the advantage gained.

In the upper reaches of the river much flooding could be saved by dredging and cleaning out the present channels, and using the material in forming embankments, provision being made for the lateral drainage by soak dykes or drains parallel with the embankments, and discharging at a level sufficiently far down the river.

Regulation and Storage of the Water.

The regulation of the water requires as much consideration as its discharge. The greater rapidity with which the rainfall is now voided leaves less to percolate through the soil for the supply of wells, springs, and brooks. Flooding is thus frequently followed by drought. The level of the water in the soil is lowered below the depth at which it can rise by capillary action to the roots of the plants, the soil becomes parched, and vegetation languishes for want of moisture, and great inconvenience is experienced from the failure of the water supply from wells and brooks.

In all river improvements the fact should be kept steadily in view, that the rainfall is only to be got rid of after making due provision for water supply, irrigation, water-power and navigation. These are none of them incompatible with good drainage. It is only necessary that proper provision should be made by sluices and

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

weirs for the discharge of floods, and by side cuts or arterial drains where the water has to be held up so high that drainage cannot be obtained for the ordinary discharge.

The value of holding up the water as an aid in the cultivation of the soil is fully recognised throughout the whole of the Fens, as also in Holland. The water in the main and subsidiary drains is maintained in summer at a uniform level of from 2 to 3 feet below the surface, by a system of sluices with doors over which any surplus flows, but which are drawn immediately the supply exceeds the demand, and the water is thus regulated to a uniform level.

Water held up in a similar manner in the higher levels would not only feed the wells but afford power for the working of the machinery of the farms through which it traverses of a far more economical character than steam.

Conservancy.

The administration of a river is hardly an engineering matter; but it is a subject which seriously affects the carrying out of any scheme of improvement. One difficulty encountered by an engineer is the restricted character of the portion of the river he has to deal with. He is called upon to devise a remedy against flooding or other evils in a particular section of a river, the remedy for which can only effectually be found by dealing with portions beyond the jurisdiction of those who have sought his aid. Attempts to bring the various bodies having control over the river into harmony, in order to carry out one comprehensive scheme, almost invariably end in failure from the diversity of interests. Every local scheme is violently opposed by all other interests; and it has been stated on reliable authority that the internecine feuds on the river Nene alone during the last fifty years have cost more than £100,000 in parliamentary and legal contests. The cost of obtaining the parliamentary powers necessary for the improvements of the Ouse have amounted during the past fifty years to upwards of £150,000; and for parliamentary proceedings alone for the Nene Valley Acts over £30,000.

An engineer is thus frequently compelled to design and execute partial works on a section of the river at great cost, where the same amount contributed to a general improvement would have effected tenfold advantage. Thus, on the Witham, within the last few years, a sum of nearly £50,000 has been expended on the middle section of the river in deepening the channel and raising the banks between Boston and Lincoln, without any provision for

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

increasing the discharging power through Boston to the sea, or relieving the lands above Lincoln by enlarging the capacity of the weirs and sluices. This was done in spite of the protest of Sir John Hawkshaw that no effectual relief could be given without extending the works downwards to the outfall in the sea. The consequence of this action has been that the water is brought more rapidly to the lower reaches without being provided with any increased means of escape, and backs up the lateral drains, bringing greater pressure on their banks than they can bear. The floods have been greater in this district since this work was done than they ever were before.

It is only after repeated attempts, spread over the last eighty years, that the various trusts below Lincoln have at length united in a common scheme for the improvement of the outfall from Boston to the sea. Provision is also about to be made for the better discharge of the water from the river above Boston, but even now this will give little relief to the city of Lincoln and the lands above.

The same process took place on the Nene. A sum of £150,000 was spent in improvements on a section of the river between Wisbech and Peterborough; and the channel was lowered and deepened without providing for the escape of the water to the outfall, the consequence being that the excavation rapidly filled up, and, in spite of this large expenditure and the consequent heavy taxation, no benefit ensued.

In the attempt made a few years ago by the corporation of Wisbech to carry out the scheme for cutting off the Horse Shoe bend through the town of Wisbech—a plan which had been recommended by every engineer who had reported on the matter for the last fifty years—they were defeated by the opposition of other interests in the river, each fearing some damage to the particular section of the river or interest represented.

The number of private Acts of Parliament in force with relation to these four rivers, even only where they pass through the Fen land, is extraordinary. The number of jurisdictions which have control over the river or the banks has accumulated till at times it is almost impossible to define their powers and rights.

The whole history of the Fen-land drainage shows the baneful result of divided administration, and teaches that no voluntary or private legislation is sufficient. The administration of the several districts protected by Fen Acts is most efficient so far as it goes, and some of the schemes in force may well form a model for any Conservancy Act that may be framed. To supersede existing

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

organizations by new boards elected on a different plan would be most injudicious. What is wanted is a consolidation of all these smaller trusts, and the uniting them by representatives sent to one common Conservancy Board, which should have control over the main river and its banks from its source to the sea, leaving the management of the interior drainage to the trusts already in existence, or, where none exist, to others formed under the powers of the Land Drainage Act. Such a system would cause as little disturbance with existing arrangements as is practicable with an efficient system of conservancy of the main outfall.

The communication is accompanied by a large map of the district, from which Plate 6 has been reduced and engraved.

[APPENDICES.

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

APPENDICES.

APPENDIX I.—Basins of the Witham, Welland, Nene, and Ouse Rivers.

Rainfall for twelve years (1869–80).

—	County.	Height above Sea.	Maximum.	Minimum.	Average.
		Feet.	Inches.	Inches.	Inches.
Wytham-on-the Hill	Lincolnshire.	167	32·83	14·40	23·88
Grantham		179	35·59	16·94	25·53
Haydor		..	34·87	14·84	25·52
Boston		24	35·53	18·22	26·02
Stubton		..	36·49	18·76	26·51
Navenby		..	36·14	18·38	26·67
Miningsby		..	33·12	17·90	26·32
Branston		136	35·40	19·07	26·56
Market Rasen		111	30·19	17·76	25·37
Gainsboro'		76	39·83	16·44	23·91
Lincoln		26	32·15	16·29	24·31
Stamford		116	34·59	16·37	25·15
Spalding		20	37·12	16·22	26·10
Hemel Hempstead	Herts.	..	36·28	21·63	28·92
Hitchin		..	30·26	17·76	25·76
Stevenage		..	31·86	18·83	26·74
Stoney Stratford	Bucks.	..	35·08	18·48	27·48
Newport Pagnell		..	33·72	17·94	25·83
Weedon Beck	Northampt'n	..	36·59	17·83	27·67
Northampton		..	36·88	17·21	27·42
Wellingboro'		154	33·40	17·21	26·24
St. Neots	Hunts.	..	31·95	15·62	25·12
Huntingdon		..	33·12	18·22	26·58
Whittlesea Mere		..	34·91	18·51	25·72
Ampthill	Bedford.	..	31·67	17·23	25·09
Biggleswade		..	31·46	16·64	24·45
Cardington		..	31·39	14·87	23·90
Cambridge	..	..	31·50	14·25	23·97
Ely	..	..	29·03	14·70	23·16
Stanground Sluice	..	..	29·24	15·68	22·54
Wisbech	..	..	38·46	19·45	27·11
Brandon	Norfolk.	..	36·26	16·70	26·43
Outwell Sluice		..	33·66	16·04	23·03
Lynn		..	33·30	20·44	27·54
Swaffham		..	40·13	20·69	27·59
Market Harboro'	Rutland.	..	39·47	18·49	29·33
Ryhall		..	36·61	16·46	26·49
Oakham		..	40·34	22·56	28·65
Average		..	34·48	17·39	26·05

Average Rainfall of thirty-eight Stations. Twelve Years, 1869–80.

Year	Inches.	
1869	26·15	23·41
1870	18·49	
1871	22·42	
1872	33·53	
1873	21·27	
1874	18·60	
1875	29·50	28·69
1876	29·77	
1877	26·92	
1878	26·63	
1879	27·81	
1880	31·54	
Average	26·05	

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

APPENDIX II.—RAINFALL at BOSTON.

Average annual rainfall at Boston respectively for five, ten, twenty, and forty-year periods.

Years.	Five-Year Periods.	Ten-Year Periods.	Fourteen and Twenty-Year Periods.	Forty-Year Periods.
	Inches.	Inches.	Inches.	Inches.
1826–30	22·10	..	22·45	..
1830–35	21·25	21·85	..	..
1836–40	24·50			
1841–45	24·64	24·73	23·25	23·82
1846–50	24·82			
1851–55	20·90	21·78		
1856–60	24·66			
1861–65	19·84	22·22	24·39	
1866–70	24·61			
1871–75	24·09	26·56		
1876–80	29·04			

The period 1861–65 in the above is the driest. In 1864 only 14·94 inches of rain fell. The next driest is 1851–55. In 1854 only 13·79 inches fell, this being the smallest fall known. The wettest period was 1876–80; the next 1846–50, but then the rainfall was 4·22 inches less than in 1876–80. The heaviest rainfall was in 1880, when 35·53 inches fell. The nearest to this was in 1872, when 32·69 inches fell; 1848, with 32·64 inches; 1876, with 31·05 inches; and 1860, with 30·69 inches. These were the only years since 1826, from which period the first records date, that as much as 30 inches of rain fell.

TWENTY YEARS' AVERAGE RAINFALL at BOSTON.

Years.	Inches.	Years.	Inches.	Years.	Inches.
1852–71	22·07	1856–75	22·80	1859–78	23·91
1853–72	22·56	1857–76	23·35	1860–79	24·15
1854–73	22·38	1858–77	23·50	1861–80	24·39
1855–74	22·56				

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

YEARLY RAINFALL at BOSTON.

Years.	Inches.	Years.	Inches.	Years.	Inches.
1826	15·43	1845	24·29	1863	18·28
1827	20·27	1846	23·40	1864	14·94
1828	28·59	1847	23·92	1865	25·63
1829	24·14	1848	32·64	1866	25·58
1830	25·90	1849	24·03	1867	25·94
1831	25·87	1850	20·11	1868	25·61
1832	22·55	1851	22·46	1869	27·26
1833	22·62	1852	25·30	1870	18·66
1834	14·66	1853	21·40	1871	23·81
1835	21·87	1854	13·79	1872	32·69
1836	21·38	1855	21·57	1873	20·21
1837	23·58	1856	19·49	1874	18·22
1838	18·95	1857	23·17	1875	25·55
1839	28·48	1858	19·00	1876	31·05
1840	18·61	1859	20·96	1877	26·14
1841	27·26	1860	30·69	1878	26·77
1842	24·73	1861	20·38	1879	25·72
1843	25·29	1862	19·98	1880	35·53
1844	21·64				

AVERAGE MONTHLY RAINFALL at BOSTON.

Years.	January.	February.	March.	April.	May.	June.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1850–59	1·46	0·95	1·16	1·42	1·35	1·90
1860–69	2·00	1·41	1·72	1·37	2·08	1·91
1870–79	1·72	1·78	1·29	1·89	1·77	2·25
1879–80	1·48	1·95	1·32	2·70	2·15	2·86

Years.	July.	August.	September.	October.	November.	December.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1850–59	2·61	2·40	1·86	2·54	1·85	1·22
1860–69	2·28	2·39	1·96	2·10	1·82	2·37
1870–79	2·53	2·57	2·61	2·03	2·37	2·07
1879-80	2·99	3·01	3·46	2·64	2·39	2·09

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

APPENDIX III.—Table showing effect of Rain in causing Floods in the Witham.

Year.	Month.	Rainfall of Previous		Rainfall Cause of Flood.		Greatest Fall in One Day.	Mean Rate of Fall Spread over		Maximum Height of Flood-water on Sills.				—
									Grand Sluice		Black Sluice		
		Four Months.	One Month.	Inches.	Days.		Four Days.	Fourteen Days.	At High Tide.	At Low Water.	At High Tide.	At Low Water.	
		Inches.	Inches.			Inches.			Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	
1852	Nov.	15·32	4·32	..	..	..	..	..	14 6	..	..	..	Highest known flood to this date.
1857	Jan.	6·38	3·13	..	..	..	..	..	14 7	..	15 9	12 6	
1862	Mar.	6·55	3·22	..	..	..	..	..	13 7	..	16 1	..	
1867	Jan.	13·12	3·67	1·66	10	..	0·19	0·15	14 0	9 6	16 1½	13 9	
1868–69	„	12·90	5·87	7·13	40	..	0·29	0·27	14 0	11 6	16 0	14 3	River full of deposit 11 feet deep against door of sluice.
1872	April	10·16	2·70	2·79	16	1·10	0·17	..	13 10	9 6	16 0	12 5	
1875	Nov.	12·30	4·90	3·13	14	0·93	0·28	0·22	15 6	10 5	16 7	13 9	River in good order.
1876–77	Jan.	13·22	4·26	3·02	14	0·46	0·43	0·21	15 11	11 0	16 9	12 6	„ „
1878	Nov.	10·24	6·94	3·47	17	0·91	0·32	0·24	13 9	12 4	15 9	..	
1880	July	9·03	3·95	4·13	17	1·55	0·39	0·27	11 9	8 9	14 3	12 0	„ „
..	Sept.	13·26	2·42	4·28	4	1·58	0·62	0·34	14 5	10 0	16 3	12 6	
..	Oct.	16·98	4·91	4·44	5	2·79	0·63	0·31	15 0	10 8	17 1	13 0	Greatest rainfall in one day ever known.
Average		..	..	..	..	..	0·37	0·25	..	..	..	..	

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

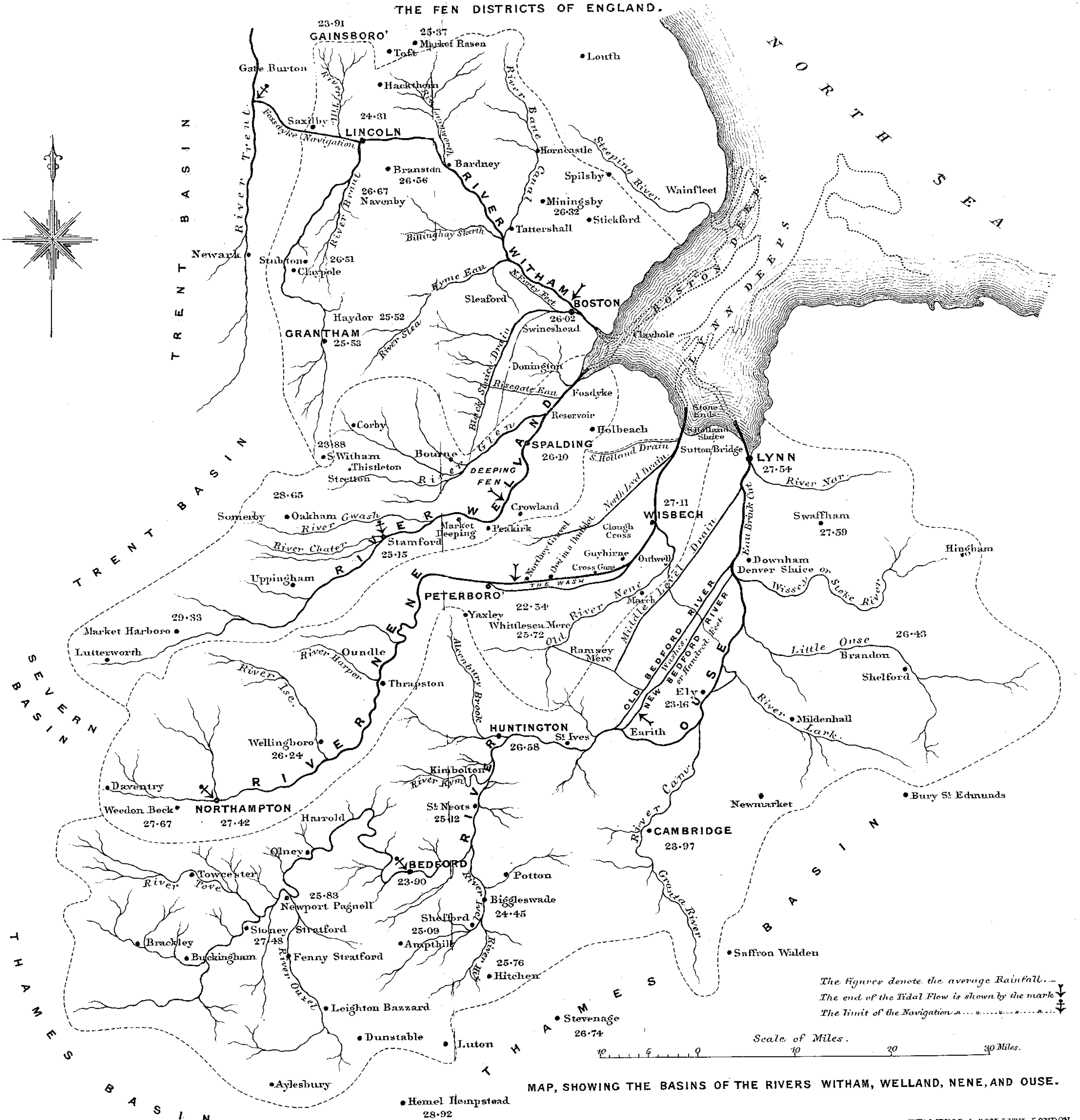
APPENDIX IV.

Name of River.	Length in Miles.		Drainage Area in Square Miles.	Acres Draining into Upper Reach.	Area of Waterway of Upper Reach.	Number of Acres to Square Foot of Channel.		Number of Acres to 1 Mile of Main Stream.	Number of Acres to 1 Mile of Main Stream and Tributaries.	Tidal Flow in Miles.	Proportion of Tidal to Fresh Water in Upper Reach.	Inclination per Mile of Surface of Stream in Floods.
	Main Stream.	Tributaries.				Upper Reach.	Lower Reach.					
					Feet.							Inches.
Witham . .	89	98	1,063	448,835	660	680	325	7,644	3,635	8	14·60	25
Welland . .	72	65	707	300,000	400	750	377	6,785	3,302	20	6·65	21
Nene . .	99	52	1,055	564,700	500	1,129·5	307	6,822	4,474	34	6·65	10·5
Ouse . . .	156	241	2,894	1,852,160	2,620	707	463	11,872	4,672	40	5·16	9
Totals and Averages	416 456	456	5,719	3,165,695	4,180	816·6	368	8,155	4,015	..	8·01	..
	872		Acres. 3,660,160									

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.

THE CONSERVANCY OF RIVERS.

THE FEN DISTRICTS OF ENGLAND.



MAP, SHOWING THE BASINS OF THE RIVERS WITHAM, WELLAND, NENE, AND OUSE.

W. H. WHEELER, DEL.T

THO.S KELL & SON, LITH. LONDON

Downloaded by [Columbia University] on [15/09/16]. Copyright © ICE Publishing, all rights reserved.