(Students' Paper No. 238.)

"Pumping-Machinery in the Fenland and by the Trentside."¹

By LAWRENCE GIBBS, Stud. Inst. C.E.

OF the lowlands which drain through the Trent in North Lincolnshire, Nottinghamshire, and South Yorkshire, and through the four Fen Rivers, the Witham, Welland, Nene, and Ouse, about 455,000 acres are at times kept dry by pumping. Probably some of this area could be well drained by gravitation, but most of it only at an expense much greater than that incurred in pumping.

For instance, Burnt Fen, in the South Level, is about 9 feet 9 inches above average low-water of spring-tides in Lynn Roads, and distant 35 miles. Assuming that the water must be kept 3 feet below the surface of the land, the total fall left will be 2.31 inches per mile. Now, suppose the water to pass through Denver Sluice and the Ouse as at present; the Ouse between Denver and the Eau Brink has a sectional area at low-water in average floods of about 1,800 square feet, and a fall of $8\frac{1}{2}$ inches per mile. Assuming that the velocity will vary as the square root of the fall, then, to discharge the same quantity as at present, the area of the river must be nearly twice as large as it now is, or 3,454 square feet, which would involve considerable lowering of the bed of the river, great alterations to the bridges, and the reconstruction of Denver Sluice and many of the interior works. Again, it has been suggested that a "low-level drain," commencing about the middle of the Eau Brink Cut, should be carried southwards through the Fens, leaving the water from the high ground of Norfolk, Suffolk, and Cambridge to pass through Denver Sluice as before. The low-water level in average floods in the Eau Brink is about 6 feet 6 inches below Burnt Fen, allowing a fall

¹ This communication was read and discussed at a meeting of the Students on the 27th of January, 1888, and was awarded a Miller Prize in the Session 1887-88.

of 2·10 inches per mile. The land to be drained is about 140,000 acres, on which $\frac{1}{4}$ inch of rain in twenty-four hours would produce 1,470 cubic feet per second, but as the sluice-doors would only be open about nine hours out of twenty-four the discharge must be at the rate of 3,920 cubic feet per second. This would necessitate a drain of 2,000 feet sectional area between the Eau Brink and Denver, gradually diminishing in area after this, also about 1,000 acres of land and subsidiary works. Thus the cost of either of these schemes would be much greater than that entailed in the provision of machinery and the working expenses of pumping.

There are many thousand acres of land in the districts in question in little better position, as regards drainage, than Burnt Fen, as may be seen from Appendix I.

In many cases also it is cheaper to retain a high lift where a lower one might be obtained.

In a report on the improvement of the Ouse between Denver Sluice and the Eau Brink Cut, 1884,¹ Mr. W. H. Wheeler, M. Inst. C.E., shows that a "low-level drain," which would only reduce the head to be pumped against 1 foot 6 inches more than the proposed river-improvement, would require a tax of 3*s.* 9*d.* per acre per annum, and effect a saving in pumping of 6*d.* per acre per annum, leaving a net annual charge of 3*s.* 3*d.* per acre; while improvements to be carried out in the Ouse would require a tax of 1*s.* 7*d.*, and effect a saving of 4½*d.*, making a net annual charge of 1*s.* 2½*d.* per acre.

As a practical illustration of this, the case of the Middle Level drainage in relation to the Manea and Welney and Sutton and Mepal districts may be cited. In 1844 an Act was passed "for improving the drainage and navigation of the Middle Level of the fens." The Manea and Welney and Sutton and Mepal districts might have been included in the land to be benefited and taxed under this Act; but, having steam-engines of their own, the proprietors preferred to remain dependent on them, and therefore were not included in the scheme. The land in the Middle Level is now taxed at 6*s.* 2*d.* per acre for main-drainage works carried out under this and subsequent Acts, and is liable to a tax of 3*d.* per acre to the Ouse Outfall Board, besides which at least three-fourths is taxed for artificial drainage. The tax on the Manea and Welney district is 4*s.* 6*d.* per acre to cover all expenses. The internal tax on the Sutton and Mepal district is about 3*s.* per acre, and it is

¹ A copy may be seen in the Library of the Institution.

liable to pay 3*d.* per acre to the Ouse Outfall Board, and 2*d.* per acre to the Denver Sluice Commissioners, so that the total tax on either of the two districts is much below that on the Middle Level for main-drainage alone.

Few of the main drains or rivers in the Fens have a less fall than 3 inches per mile, and even with this much expense is incurred in keeping the channel from silting up or being choked with weeds.

It appears, then, that much fen-land can be more economically drained by machinery than by gravitation.

WINDMILLS.

Before the introduction of steam-power, windmills working scoop-wheels were largely used for drainage in the Fenland; but not in the lowland draining into the Trent, where scoop-wheels worked by horses were once the general means of drainage.

The windmills may be divided into two classes, according to size. In the larger ones, which raise the water into the main drains, the space not occupied by the gearing is used as a house; the scoop-wheel is outside in a wooden casing. The machinery and the scoop-wheel, except for a few bolts and straps, were made entirely of wood; but few can be found now in which iron has not been substituted in some parts.

The mill has four sails of canvas spread on lattice-work; the inclined shaft which carries the sails has a wheel with wooden teeth gearing into a wheel on the vertical shaft of the mill; there is another wheel at the bottom of this vertical shaft which gears into a wheel on the horizontal shaft carrying the scoop-wheel. As there are no means of furling the sails when the mill is at work, the wheel on the sail-shaft is fitted with a wooden brake worked by a chain from below. The sails are kept to the wind by a winch fixed at the bottom of three lever arms, one of which goes to the back and one to each side of the mill-head; a chain attached to the winch can be fixed to the heads of piles, of which there are ten or twelve round the mill.

The floats of the scoop-wheel are seldom more than 15 inches wide; they are placed much closer together than is general with those driven by steam, and are formed of a single plank fixed to the rim and supported at the outer end by a small bar clenched to the rings. The race is of brickwork up to about the middle of the wheel, and above this is a wooden case closely covering the wheel.

In a mill near March the sails are each about 36 feet long and 7 feet 6 inches wide; the vertical shaft is 16 inches square, and the horizontal shaft carrying the scoop-wheel and lowest gearing-wheel 20 inches square. The scoop-wheel is 22 feet in diameter, and the floats are $9\frac{3}{4}$ inches broad; the sail-shaft and the rim of the scoop-wheel are of cast-iron. About fifty of the large windmills remain in the Fenland, most of them in the Middle Level.

There is, however, very little land entirely dependent on wind for its drainage. Many of the mills are fitted with a pulley, so that a portable engine may be attached when necessary. Some have a fixed engine which works the wheel in calm weather, and some are in districts where a separate steam-engine does most of the work, and is capable of doing all.

In the Littleport and Downham district, which is now well drained by two steam-engines, there were at one time seventy-five windmills; and the Deeping Fen district, now drained by two steam-engines at Pode Hole near Spalding, was, before 1825, "kept in a half-cultivated state by the help of forty-four windmills."

The smaller windmills have an open wooden framework to support the sails and gearing, and a scoop-wheel about 12 feet in diameter, which, unlike the larger mills, is within the framework; they lift the water from the fens into the engine-drains, whence it is pumped into the main drain or river. Several of these may be seen in the Middle Fen district near Ely. In two cases a windmill drives a small centrifugal pump, draining about 30 acres of land.

Windmills are used throughout the Fenland to drain brick-pits; the shaft carrying the sails is fitted with a crank to which is attached a vertical rod working an ordinary suction and lift-pump about 6 inches in diameter and 9 inches stroke. The steam-engines in the Fenland and in the Trent lowlands, in all but two cases, now drive either scoop-wheels or centrifugal pumps.

SCOOP-WHEELS.

A scoop-wheel may be likened to an undershot water-wheel, turned round in the opposite direction, so that instead of being rotated by the water flowing through the race from the mill-pond, it pushes the water up the race from the drain behind to the river in front.

In the scoop-wheel, Fig. 1, *a* is the shaft, *b* the boss, *c c* the spokes, *d d* the rim, *e e* the start-posts or starts, *f f* the float-

boards. The spokes and rim, and ironwork connecting them, are here called the framework, and the starts and float-boards together, the floats or ladles.

There are three general ways of constructing the framework, which in all cases, excepting the wheel at Upwell, is of cast-iron. By the first method, the spokes are each in one casting through the width of the wheel, the outer limbs being of a T section with connections of T section at the shaft and ladle ends, and + section in the middle; they are bolted transversely to the rims and longitudinally to a cellular boss keyed on to the shaft. By the

FIG. 1.

DRAINAGE ENGINE WITH SCOOP-WHEEL NEAR TATTERSHALL.

Scale 11 feet = 1 inch nearly.

second, in which some of the large wheels by the Trentside, and a few on the Witham were made, the framework is in four castings, two forming each side of the wheel; they are bolted and held together by straps, and are keyed to the shaft, being independent of the other side of the wheel. By the third, used for most of the wheels in the Fenland since about 1845, each spoke is a separate casting, either of a rectangular or T section, bolted transversely to the boss, which is keyed on to the shaft, and to lugs cast on the rim, or cast together with a segment of the rim, the spokes in some cases being connected by bolts and distance-pieces. In all

the old wheels the shaft is carried on bearings with no means of adjustment except by packing.

The rim is cast with sockets, through which the start-posts pass; these are generally of oak, and are secured at the rim with a pin of iron or of oak, passing through the start and through, or at the back of, the rim, and to each other by iron rings about $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch, passing round the wheel and bolted to each start.

In the Haddenham wheel, near Ely, the starts are carried through the rim to the spokes, which are cast with holes to receive them, and are wedged one way at the rim and the other at the spokes. In the Manea and Welney district wheel, the starts are held together by short bolts passing from start to start with a nut at one start and a head at the other.

The float-boards are of fir, 1 inch or $1\frac{1}{2}$ -inch thick, nailed or bolted to the starts, of which there are in almost all cases two to each float. Sometimes the boards are held between an iron strap and the start; but the wood always tends to rot first where in connection with the iron. The floats at the circumference are from 1 foot to 3 feet apart, fixed at an angle to the radius so as to lessen the tendency which the wheel has to lift the water higher than necessary.

In many wheels boarding is fixed to the rims so as to form a drum, to lessen the loss of water from flowing back over the inner end of the floats. The wheel-race and breast are of stonework. In front of the wheel, a door or pair of pointing doors keeps out the water when the wheel is not working. At the back of the wheel a grating of vertical iron bars prevents the entry of floating weeds and rubbish.

All the old wheels are driven by low-pressure condensing beam or side-lever engines; but lately horizontal, vertical, and in some cases portable engines have been put down. A pinion on the crank-shaft of the engine gears into, either a toothed wheel on the shaft of the scoop-wheel, or toothed segments bolted to or cast on the scoop-wheel rim. In the last case when the teeth wear out, the whole of one side of the wheel has to be taken to pieces to replace them. The ratio of the engine speed to that of the scoop-wheel in the old engines was generally 3 or 4 to 1; in the later engines it has been increased to 6 or 7 to 1. The speed at which the wheels are worked is very variable, the average being about 8 feet per second at the circumference. Most of the old engines have been altered in late years, the steam-pressure having been raised, and the cylinders fitted with variable expansive valve-gear. Where the station consists of a single engine working a scoop-

wheel, the buildings are necessarily of the same arrangement, the engine-room being in the middle with the boilers at one side and the scoop-wheel at the other.

Most of the chimneys are from 50 feet to 70 feet high, though some of them on the Witham and Trentside are from 100 feet to 130 feet high; and they are usually, and often the other buildings, carried on piled foundations.

CENTRIFUGAL PUMPS.

Vertical-spindle centrifugal pumps, often called turbine pumps, are the rule where a large area has to be drained, there being only three cases where a horizontal-spindle pump has been used for the drainage of over 1,000 acres.

Of the former pumps those first put down were chiefly of the double-inlet type, with a disk of metal in the centre of the fan, and an annulus at each side connected to the disk by the vanes. They were placed in a well of masonry and iron, closed at the top, bottom and three sides, except for the two suction pipes, the water going out in front in a horizontal direction.

Lately, the single-inlet type of vertical-spindle pump has been adopted. Here the pumps are placed in a circular brick well or iron case; like the last they are always below, or partly below, the drainage water when starting; but the inlet is generally carried down a few inches, so that the water can be pumped to below the level of the fan. The gearing between the engine and the pump-spindle is arranged in various ways.

Nearly all horizontal-spindle pumps in the Fenland and Trentside are driven by portable or semi-portable engines through belting. The fan is in an iron case above the water to be raised, and usually above the level of the river into which the water is discharged.

THE TRENT.

About 59,000 acres of the lowlands which drain through the Trent are treated by steam-power.

As the Trent is subject to great fluctuations irrespective of the tides, the difference between low-water of ordinary spring-tides and low-water with a heavy fresh running being 10 feet at Ravensfleet and 15 feet at the Marton engine, all this land has, at times, a natural drainage.

Much of the land on the Trentside has been warped by letting in the tidal water, which is heavily charged with mud. The object

of warping is to improve the land rather than to raise it. Should the land be peat, the improvement is great; but the peat is often compressed as much or more than the thickness of the warp with which it is covered. There are two warping schemes now being carried out, one for the improvement of part of Brumby Common near Althorpe, and the other for warping some land between By Carrs Dyke and the high land of the Isle of Axholme.

Of the 59,000 acres drained by steam, 21,000 are on the east side, and 38,000 on the west side of the Trent. An area of 52,850 acres is drained by scoop-wheels, 4,550 acres by centrifugal pumps, and 1,600 acres by a bucket-pump at Marton.

On the east side, the pumping-station farthest up the river is at Torksey, 35 miles from Trent Fall. It is on the south side of the Foss Dyke, and west of the lock which, in floods, keeps out the Trent water, and in summer holds up the water in the Foss Dyke for navigation. It consists of an expansive condensing beam-engine of 60 nominal HP. put down in 1852, and working with from 20 to 25 lbs. steam per square inch; this drives a scoop-wheel 35 feet in diameter, with floats 1 foot $11\frac{1}{2}$ inches wide and dip of about 4 feet 6 inches. There are drained through it 9,260 acres of taxable land, and also some high land. The highest known flood in the Trent at this spot was in 1876, when the water rose to the middle of the wheel, giving a head of 17 feet 6 inches.

Marton engine is on the Trent bank about 2 miles below Torksey; it drains 1,600 acres of taxable land, and besides this receives the water from about 2,000 acres of high land. The engine, erected in 1864, is a single-acting beam-engine, of 40 nominal HP., working a bucket-pump 5 feet in diameter and with a stroke of 7 feet 6 inches. This engine often lifts the water 5 or 6 feet above that in the Trent.

Ravensfleet engine, erected in 1843, is also on the east bank of the Trent, about 5 miles below Gainsborough, and 20 miles from Trent Fall; it drains about 3,850 acres of taxable land, and in high floods has to admit and pump out the water from the catch-water drain which should protect it, rather than that it should burst its banks. It is a beam-engine of 40 nominal HP., and works a scoop-wheel 35 feet in diameter, with curved floats 2 feet wide and 5 feet dip, of $\frac{3}{16}$ -inch iron on wooden starts. At the back of the wheel is a wooden casing, with an opening so arranged that the water may not strike the floats till both are travelling in nearly the same direction. In front is a door formed of several wooden flaps hinged together horizontally, which, when the wheel

is working, float in the water, and rise to a vertical position as soon as the wheel stops.

East Butterwick engine was erected in 1882 for the better drainage of 3,250 acres of land, which before then had a natural drainage through two sluices into the Trent. The engine-and-pump-house is of wood, built on piles over the drain just behind the lower sluice, which is 13 miles from Trent Fall. At present, there is one double-cylinder, semi-portable engine, driving, through a belt, a horizontal-spindle centrifugal pump. The suction and delivery pipes are 21 inches in diameter. Room has been provided in the building for another engine and pump. The cost of the building and machinery was £1,400.

The Sturton engine, erected in 1847 on the west side of the Trent, drains about 9,000 acres of land, and receives some high-land water; it is a beam-engine of 43 nominal HP., working a scoop-wheel 26 feet 6 inches in diameter, with curved iron floats 2 feet 3 inches wide.

The Soss engines drain Gringley and Misterton Carrs, about 6,100 acres; there are two beam-engines and two scoop-wheels, one erected in 1828, and the other in 1839.

The South Level engine drains 7,270 acres between the Torne River and the River Idle. The engine is an old side-lever engine of 40 nominal HP., placed in its present position in 1858; it drives a scoop-wheel 30 feet in diameter, with floats 2 feet 11½ inches wide at about 4½ revolutions a minute; it has seldom more than 5 feet lift; the water is discharged into the New Idle River, which joins the Trent at Keadby, 9 miles from Trent Fall.

The North Level engines drain 10,660 acres of land between the Stainforth and Keadby Canal and the Torne River. This land, with that drained by the engine last mentioned, is under the Corporation of the Level of Hatfield Chase. The station was erected in 1864. There are two compound condensing beam-engines of 50 nominal HP. each, coupled at an angle of 90° to a crank-shaft carrying the fly-wheel and a pinion which gears into a wheel with wooden cogs on a shaft going through the engine-house wall, and carrying a pinion gearing into teeth cast with the rim of the scoop-wheel. The high-pressure cylinder of each engine is 20 inches in diameter with a 4-foot 4½-inch stroke, and the low-pressure cylinder is 35 inches in diameter with a 6-foot stroke.

The engine-beams are of cast-iron, carried by a beam built into the engine-house walls, which are 27 inches thick, and supported by a pair of columns under each beam centre.

The scoop-wheel is 33 feet 3 inches in diameter, with thirty-six wooden floats 6 feet wide, 7 feet 10 inches long, with 7-foot dip. With the full dip of 7 feet and a lift of 7 feet the floats enter the water at an angle of 13° , and leave it at an angle of 31° . There are four double-flued boilers, each 20 feet long and 7 feet in diameter, worked at from 20 to 30 lbs. steam-pressure per square inch. The buildings cover 3,990 square feet of ground. At 4 revolutions, with a dip of 7 feet and deducting 8 per cent. for leakage, the scoop-wheel would discharge 326 tons a minute, and with 7 feet lift would raise water equal to 155 HP. The cost of the buildings and machinery was £9,000, or £58 per estimated effective HP.

THE WITHAM.

Of the land draining through the Witham, excluding a few small districts above Lincoln, about 87,000 acres are under steam-drainage, 40,000 acres being drained by scoop-wheels, and 47,000 by centrifugal pumps. Between 3,000 and 4,000 acres are, to some extent, drained by windmills.

In the first, third and fifth Witham districts, which comprise all the low land below Lincoln draining through the Grand Sluice, there are three centrifugal pumps which drain together 4,700 acres, the remaining 33,100 acres are drained by thirteen scoop-wheels, in all cases but one driven by beam-engines. On Billingham Skirth there are two small horizontal-spindle centrifugal pumps worked by windmills, draining together about 60 acres of land.

Fiskerton engine, on the Witham, 24 miles from the Grand Sluice, drains 1,410 acres of taxable land, but receives the water from a much larger area of high land, and has also the leakage through about 9 miles of river bank to contend with. The engine was erected in 1862, and is of 35 nominal HP. with one horizontal cylinder 24 inches in diameter with a 4-foot stroke; it works a scoop-wheel 31 feet in diameter, with wooden floats 2 feet 4 inches wide. The steam-pressure is 65 lbs. per square inch, the engine running about 32 revolutions to 5 of the scoop-wheel. It is not of sufficient power for the district, which, in heavy floods, is much troubled by the highland water, and that which soaks through the Witham bank.

At Timberland Fen, an engine and centrifugal pump were substituted in 1881 for a scoop-wheel worked by a beam-engine which was of insufficient power. The engine is a high-pressure condensing beam-engine of 50 nominal HP. The cylinder is

[THE INST. C.E. VOL. XCIV.]

T

36 inches in diameter with a 6-foot stroke. The engine makes 17 revolutions to 175 of the pump. The fan is of gun-metal 4 feet in diameter. The area of the fen drained is 3,200 acres.

Tattershall engine, erected in 1855, is on the left bank of the Witham 11 miles from the Grand Sluice. It drains between 2,000 and 3,000 acres, and receives some highland water. It is a small beam-engine working a scoop-wheel 24 feet in diameter, and 1 foot $3\frac{1}{2}$ inches wide; the scoop-wheel has thirty-six floats of 1-inch fir. The estimated weight of the wheel, shaft, and the toothed wheel which is on the same shaft as the scoop-wheel, is about 7 tons.

The Kirkstead engine, which drains about 700 acres of land on the east side of the Witham, is arranged to drive a flour-mill placed between the engine-house and the scoop-wheel.

The Lade Bank engines and centrifugal pumps, for the drainage of about 35,000 acres, including the East Fen, some lowland in Wrangle, and 5,000 acres beyond the Steeping River, have been described in a Paper by Mr. E. Welsh, M. Inst. C.E.¹

In the southern part of the Black Sluice district there are four horizontal-spindle centrifugal pumps, three on the South Forty-Foot, and one on Hammond Beck, draining respectively 1250, 400, 800, and 1250 acres.

The Morton Fen and Bourn North Fen engines drive scoop-wheels.

In the second and sixth Witham districts, which are also under the Black Sluice Commissioners, there are three small horizontal-spindle centrifugal pumps, and a few windmills. South Kyme Fen is drained by a vertical-spindle centrifugal pump driven by an old beam-engine, which formerly worked a scoop-wheel in the same buildings.

THE WELLAND.

The Welland receives the water from about 37,600 acres of fens drained by steam. Of this area Deeping Fen comprises 30,000 acres. The rest is made up by three districts, one of about 1,700 acres, having a scoop-wheel lifting into Vernatts drain $\frac{1}{2}$ mile below Pode Hole; the second about 5,000 acres with a scoop-wheel lifting into a drain which joins the Glen near the Reservoir; and the third, Bourn South Fen of 850 acres, is drained by a scoop-wheel and portable engine discharging into the Counter Drain through a culvert which passes under the Glen.

¹ Minutes of Proceedings Inst. C.E. vol. xxxiv. p. 178.

The Deeping Fen engines at Pode Hole were erected in 1825. There are two beam-engines of 80 and 60 nominal HP. respectively, running side by side, with a 21-inch wall between, each working a scoop-wheel through a pinion on the crank-shaft, and toothed-wheel on the shaft of the scoop-wheel. The 80-HP. engine has a cylinder 44 inches in diameter, with an 8-foot stroke of piston, and the 60-HP. engine a 45-inch cylinder with a stroke of 6 feet 6 inches. Both engines were altered and the six boilers renewed between 1873 and 1883.

The 80-HP. engine drives a wheel 31 feet in diameter, with floats 5 feet wide, and has a full dip of 7 feet. The wheel driven by the 60-HP. engine is also 31 feet in diameter, with floats 5 feet wide, but the dip is 5 feet 6 inches.

In front of each wheel is a movable breast and floor, which is raised or lowered according to the state of the water. In Plate 12, Fig. 1, *a* is the wooden floor hinged at *b* to the cast-iron curved plate *c*, which slides in grooves *d* at each side of the race. The floor is raised by two winches which gear into racks fastened to the upper ends of two bars *e*; as the floor rises, the end farthest from the scoop-wheel slides under an iron plate *f* which is hinged to the fixed floor. The hinge bars are carried about 3 feet beyond the plate *f*, and the floor *a* is hung to them but allowed to slide, so that, when the floor is raised, *a* and *f* are kept in a straight line.

There is also a sliding shuttle at the back of each wheel to regulate the supply of water; it is made of wood and worked by toothed-gearing from the engine-house.

THE NENE.

The greater part of the basin of the Nene has a natural drainage, only about 9,300 acres being under pumping. On the south or right bank of the river, with the exception of the Waldersea and Redmoor districts, all the lowland from Peterborough to Wisbeach drains into the Ouse, principally through the Middle Level Sluice. Below Wisbeach the drainage also goes to the Ouse till the newly enclosed land called Wingland is reached; this drains into the Nene through a sluice near Sutton Bridge.

On the north or left bank, the whole of the land from Peterborough to the North Level Sluice, 5 miles below Wisbeach, is in the North Level drainage district; and, except a small area near Wisbeach, has a natural drainage. In wet seasons, however, much of this land, particularly in Borough Fen, near Peterborough, and

at Cross Guns on the Nene, 10 miles below Peterborough, is liable to flooding.

In 1881 a bill was brought before Parliament for the erection of a pumping-station at the outfall sluice capable of discharging $\frac{1}{4}$ inch of rain in twenty-four hours on the whole district of 76,500 acres. Centrifugal pumps were proposed to be used; but this and other schemes were opposed and not carried further.

The Waldersea District, containing 5,050 acres, is drained by two engines on the bank of the Nene, 17 miles from Wisbeach Eye. The older one, erected in 1832, is a Cornish beam-engine of 70 nominal HP. The steam-cylinder is 40 inches in diameter, with an 8-foot stroke. The maximum pressure is 35 lbs. per square inch, the cut-off $\frac{1}{4}$ stroke, and the speed 9 strokes a minute. This engine works a bucket-pump 62 inches in diameter, and of 7 feet 6 inches stroke. The bucket-valve is an iron ring, and the suction five circular india-rubber valves.

To supplement this a vertical-spindle centrifugal pump was erected in 1883. The fan is 3 feet 10 inches in diameter, and is worked through one pair of bevel-wheels, geared 3 to 1, by a single-cylinder inclined condensing engine, using steam at 65 lbs. pressure per square inch, and cutting off at $\frac{1}{4}$ stroke. The boiler, 25 feet 6 inches by 5 feet 6 inches, is in the boiler-house of the old engine. The engine is in a wooden building with the pump in an iron case outside.

These engines, with those at Wisbeach North Side and Redmoor, have the disadvantage of being close to the tidal Nene, so that, when the tide is up, they must either stop pumping or lift the water to a greatly increased height. The lift at the Waldersea engines is generally about 8 feet at low-water.

Redmoor, a district of 1,780 acres, was formerly drained by two windmills, one lifting behind the other. In 1878 a vertical-spindle centrifugal pump was erected, working in an iron well, and driven, through one set of bevel-wheels, by a semi-portable engine in a corrugated-iron shed.

Wisbeach North Side engine was erected in 1884 for the better drainage of about 2,500 acres, which in ordinary times discharge naturally through the North Level Sluice. It is a vertical, single-cylinder engine, driving, through a pair of bevel-wheels, a vertical-spindle centrifugal pump having a fan 3 feet 8 inches in diameter.

THE OUSE.

About 258,600 acres of land are artificially drained through the Ouse. This area includes 132,900 acres in the South Level, being all the Fenland to the east of the Hundred-Foot River, 89,400 acres in the Middle Level lying between the Old Bedford River and the Nene, and draining into the Ouse through the Middle Level Sluice at the upper end of the Eau Brink Cut; and the remainder is made up of the Manea and Welney, and Sutton and Mepal districts; Downham, Bardolph, Magdalen, and Marshland Fens, and two small districts near Denver Sluice, one pumping into the Old Bedford River and the other into a drain which joins St. John's Eau, and discharges into the Ouse 4 miles below Denver Sluice.

The Middle Level, which includes (with the exception of the Manea and Welney, and Sutton and Mepal districts) all the lowland between the Ouse and the Nene south of a line drawn (roughly) from Denver Sluice to Guyhirne, at the lower end of the Nene Washes, was in former days principally drained by windmills, of which several are still left. Under an Act passed in 1844 the Middle Level Main Drain was cut, the interior drains were cleaned out, and an outfall sluice was built where the Main Drain joins the Ouse at the head of the Eau Brink Cut, 13 miles from Lynn Roads. It was expected that these works would give the Level a natural drainage; but the expectation has not been fulfilled for at least three-fourths of its area. In 1862 the outfall sluice failed,¹ a dam was built across the drain, and the drainage-water carried over by siphons; this arrangement was superseded by a new sluice in 1877, and the Level is now taxed to the extent of more than 6s. per acre, not counting the cost of pumping.

The drainage is partly by scoop-wheels and partly by centrifugal pumps; about forty windmills are still used, many of them having pulleys attached so that the scoop-wheel may be worked by a portable engine.

Whittlesea Mere was first drained in 1852, when a horizontal-spindle centrifugal pump was put down and worked through gearing by a 25 nominal HP. beam-engine; this was the first centrifugal pump used for drainage in the Fenland. Owing to the subsidence of the land through drainage, this engine was after a time found too small, and the present engine and centrifugal pump were erected in 1877. The engine was made from the same patterns as the Prickwillow engine described later on, and is

¹ Minutes of Proceedings Inst. C.E. vol. xxii. p. 497.

geared with the pump in a similar way. It drains Whittlesea Mere, Holme, Yaxley, Stilton, and Denton Fens, about 6,500 acres in all, and receives some highland water; it pumps into Bevill's Leam, one of the Middle Level main drains, which eventually discharges into the Ouse through the Middle Level Sluice, from which the engine is 30 miles distant.

Glassmoor with some land to the north of Bevill's Leam, a district of between 5,000 and 6,000 acres, is drained by a vertical-spindle centrifugal pump which was erected in 1859. The pump is of the double-inlet type, and is driven by a pair of single-cylinder engines, one at each side of the pump-well. Steam is supplied at from 30 to 40 lbs. pressure per square inch by two boilers, each 6 feet in diameter and 20 feet long. The lift is seldom more than 5 feet.

Middle Moor is drained by a centrifugal pump driven by a pair of vertical engines; Blackbush district by a centrifugal pump driven by a horizontal engine; and Connington Fen by a centrifugal pump driven through a pair of bevel-wheels by a portable engine. Besides these there are about half a dozen small centrifugal pumps in different parts of the Level.

Ramsey Hollow, White Fen, Ranson Moor, West Fen, and Binnimoor Fen are drained by scoop-wheels driven by beam-engines.

Upwell engine, with the help of two windmills, drains a district of about 9,500 acres between the Old Bedford and Sixteen-Foot Rivers; the station, erected in 1877, consists of two single-flued boilers 20 feet long and 5 feet in diameter, supplying steam at about 60 lbs. pressure per square inch to a compound-condensing horizontal engine which drives, at about $5\frac{1}{2}$ revolutions a minute, an iron scoop-wheel 24 feet in diameter and 4 feet wide, with 18 curved iron floats and shrouded sides.

The South Level contains 147,000 acres of land, taxable to the Denver Sluice Commissioners; it is divided into districts varying from a few hundred to 28,000 acres; most of these have been under steam-drainage for forty years, and some for a longer period. The old course of the Ouse, which, however, has been straightened in some places, forms the principal main drain, part going by the name of the Ten-Mile River, and part being known as the Old West River. Four upland rivers, the Cam, Lark, Brandon, and Wissey, pass through the Level between embankments, and also serve as main drains. The tide flowing up the Ouse and Hundred-Foot River is prevented entering the South Level by Denver Sluice, 23 miles from Lynn Roads, through which the

drainage water of the Level passes during the latter part of the ebb-tide.

The Littleport and Downham district, the largest in the Level, contains 28,000 acres of taxable land, and also receives some high-land water. It is drained by two engines, each driving a scoop-wheel, one lifting into the Hundred-Foot River and the other into the Ten-Mile River.

The former engine, erected in 1830, underwent great alterations in 1881; it is a beam-engine with cylinder $43\frac{1}{2}$ inches in diameter and of 8-foot stroke, using steam at 17 lbs. maximum pressure per square inch, and fitted with variable-expansion valve-gear, the cut-off being fixed according to the height of the water in front and behind the wheel. The crank-shaft of the engine carries a pinion gearing into toothed-segments bolted to the scoop-wheel rim. The scoop-wheel, which was a new one in 1881, is 50 feet in diameter and 3 feet 4 inches wide; it has sixty floats 8 feet long and having 6 feet full dip; in front of the wheel is a movable iron breast, but no movable floor, as at the Pode Hole engines. Behind the wheel is a shuttle or slacker, which, however, is never used, but is so arranged that the water can be entirely shut off. The movable breast can be raised 8 feet above the delivery sill, which is 12 feet above the bottom of the wheel.

The highest recorded flood in the Hundred-Foot River was on the 28th of October, 1882, when the water rose to 22 feet 6 inches above the bottom of the wheel. The engine makes from 19 to 21 revolutions a minute, and is geared 7 to 1 with the scoop-wheel. Steam is supplied by three double-flued boilers each 7 feet in diameter and 27 feet long. The buildings cover an area of 4,700 square feet.

The scoop-wheel, with 4-foot dip, at 3 revolutions, and deducting 8 per cent. for leakage, would discharge 133 tons a minute, and with 10-foot lift would raise water equal to 90 HP.

The Ten-Mile engine, erected in 1842, is a beam-engine, with cylinder 44 inches in diameter and 8-foot stroke; it drives a wheel 43 feet 8 inches in diameter and 3 feet wide; the highest recorded lift here, on the 21st of December, 1881, was 13 feet 5 inches.

Over and Willingham Fens, Haddenham, Cottenham, Water-beach, and Swaffham and Bottisham districts, and Burwell Fen are all drained by scoop-wheels. The Swaffham and Bottisham engine was substituted for one erected in 1820, which was probably the first instance of drainage by steam in the Fenland.

The Middle Fen district has a taxable area of 11,000 acres. It includes the Middle Fen and Soham and Isleham Fens, besides

which a large quantity of highland water runs into the Fen, and in times of heavy floods the water from Soham Mere has also to be discharged by the Middle Fen machinery, the area then drained being 25,000 acres of land. The district includes probably the lowest land in the Fens, some of it being not more than 3 feet above the sill of Denver Sluice, where the highest recorded flood reached 20 feet above the sill. The water in the Lark in this case would be 17 feet above the level of some parts of the Fen. The drainage is performed by two steam-engines at Prickwillow, pumping into the Lark, and by three large windmills, two on the Lark bank and one on the bank of the Ouse near Ely. There are also about thirty small windmills within the district pumping into the engine drains. Of the engines at Prickwillow, one erected in 1833 is a condensing side-lever engine of 60 nominal HP. using steam at 6 lbs. pressure, and driving an ordinary scoop-wheel 33 feet 6 inches in diameter and 2 feet 1 inch wide. A new engine (Plate 12, Figs. 2, 3, and 4), which now does most of the work, was started in 1880, close to the old one, to pump water out of the same drain. It is a compound condensing beam-engine of 60 nominal HP., using steam at about 65 lbs. pressure per square inch, and driving a vertical-spindle centrifugal pump. The high-pressure cylinder is 15 inches in diameter, length of stroke 3 feet $1\frac{1}{2}$ inch, and is fitted with variable-expansion valve-gear; the low-pressure cylinder is 25 inches in diameter with a stroke of 4 feet 6 inches; both cylinders are steam-jacketed; the steam after leaving the low-pressure cylinder is condensed by a jet condenser. The fan is of gun-metal 5 feet 4 inches in diameter and 14 inches deep; it is placed in a brick well 6 feet 8 inches in diameter. With a lift of 15 feet the fan makes 128 revolutions to 38 of the engine. The weight of the water above the fan is counteracted by letting the water through holes into the space between the fan and the casting at the bottom of the pump-spindle. There are two double-flued boilers each 23 feet long and 6 feet 6 inches in diameter, with four Galloway tubes to each flue.

The machinery was erected under the advice of Mr. Carmichael, the Superintendent of the South Level, for the Middle Fen Commissioners. The buildings were not carried out exactly as given, but the arrangement of the machinery is the same; the iron case shown above the pump-well has been removed, and a small wooden shed substituted.

The following are the results of trials made with both the old and the new engines. The discharge was measured over a weir built in the basin between the engines and the River Lark.

EXPERIMENTS with NEW ENGINE and CENTRIFUGAL PUMP, 3rd JULY 1880.

Steam Pressure per Square Inch.	Revolutions of Engine.	Lift.	Water Lifted per Minute.	Effective HP.	Indicated HP.	Efficiency.
Lbs.		Ft. Ins.	Tons.			
66	31·1	9 7	74·18	48·24	90·34	0·534
65	32·2	10 0½	82·80	56·43	107·70	0·525
65	32·8	10 4½	82·80	58·28	108·30	0·546
61	32·7	10 8	74·18	53·73	102·40	0·527
63	33 0	10 11	74·18	54·99	103·30	0·532
67	34·0	11 10	74·18	59·57	114·60	0·519
67	35·4	12 5½	69·20	58·41	116·00	0·504

EXPERIMENTS with OLD ENGINE and SCOOP-WHEEL, 19th JULY, 1880.

Steam Pressure per Square Inch.	Revolutions of Engine.	Lift.	Water Lifted per Minute.	Effective HP.	Indicated HP.	Efficiency.
Lbs.		Ft. Ins.	Tons.			
6	25·5	9 8¼	73·0	48·02	108·7	0·442
6	24·5	9 9½	73·0	48·41	103·4	0·468
6	24·5	9 9½	70·9	47·11	103·7	0·454
6	23·5	9 10½	68·9	46·30	97·7	0·475

In the experiments with the new engine steam was cut off at $\frac{1}{2}$ stroke.

The cost of machinery and buildings was £4,917; the effective HP., when steam is not cut off till $\frac{5}{8}$ stroke, is 68; this gives £72 per HP.

The Burnt Fen district has a taxable area of 14,000 acres, 15,000 being the area from which the water is discharged by the engines. The district lies between the Lark, the Brandon, and the Ten-Mile Rivers, and is bounded on the east by Mildenhall Fen, and some small districts pumping into the Brandon River. There are two pumping-stations, one at each side of the Fen. The station on the Brandon River consists of an old side-lever engine of 40 nominal HP., driving a scoop-wheel 34 feet 4 inches in diameter, and 2 feet wide. The present engine on the Lark, erected in 1883, generally called the Duck engine, drives a centrifugal pump. It is a horizontal compound condensing engine with two cylinders, 18 inches and 30 inches in diameter, with a stroke of 3 feet;

steam is used at from 50 to 60 lbs. pressure per square inch, and is cut off in the high-pressure cylinder at about $\frac{3}{8}$ stroke. The engine makes about 60 revolutions a minute, and is geared 10 to 18 with the pump, which is of gun-metal, of the single-inlet vertical-spindle type, 6 feet in diameter, and $12\frac{1}{2}$ inches deep, working in a brick well.

Hunt's Sluice engine is on the right bank of the Ten-Mile River, 2 miles from Denver Sluice; it drains between 4,000 and 5,000 acres of fen-land, none of which is nearer to the engine than 4 miles; the water is brought to the engine by a drain called Sam's Cut. It is a compound semi-portable engine, and drives through a pair of bevel-wheels a vertical-spindle centrifugal pump in an iron case.

Padnal upper and lower engines drive vertical-spindle centrifugal pumps, draining respectively 1,530 and 850 acres.

The Mildenhall, Lakenheath, Hockwold, Feltwell, and Methwold Fens, and Methwold Severals, are drained by scoop-wheels.

The Manea and Welney, and Sutton and Mepal districts, and Downham, Bardolph, Magdalen, and Marshland Fens, are all drained by beam-engines driving scoop-wheels.

In 1870 the defects of scoop-wheels as then constructed, with calculations accounting for their low efficiencies, irrespective of the work lost by friction in the engine and gearing, with suggestions for their improvement, formed the subject of a series of Papers by Mr. W. Airy, M. Inst. C.E.,¹ and Papers on centrifugal pumps have been published in the Minutes of Proceedings of the Institution.² Particulars as to the subsidence of fen-land after drainage have been given in a Paper on "The Drainage of Whittlesea Mere," by Mr. W. Wells.³

From levels taken in 1883, Burnt Fen and Whelp Moor were found to have sunk on the average 4 feet 9 inches since 1809, of which 3 feet 6 inches occurred between 1809 and 1860.

As an alternative for lengthening the floats or lowering the wheel, consequent on the shrinkage of the fen-land, where scoop-wheels are used, an assistant wheel, for which a patent was taken out in 1872 by the driver of the Haddenham engine, has been put down at the Haddenham and Burwell engines. It is an iron wheel with curved ladles, driven at Haddenham from the toothed-

¹ *Engineering*, vol. ix. p. 183 *et seq.*

² Minutes of Proceedings Inst. C.E. vol. xxxii. p. 26; vol. xlvii. p. 267; and vol. liii. p. 249.

³ The Journal of the Royal Agricultural Society of England, 1860, vol. xxi. p. 151.

segments on the scoop-wheel through gearing and belting, and at Burwell from the crank-shaft by a chain; it is fixed in a race at the back of the scoop-wheel, and, dipping from 1 foot to 2 feet lower, lifts the water up to the scoop-wheel.

The Author is indebted to Mr. W. H. Wheeler, M. Inst. C.E., and to Mr. G. Carmichael of Ely, for many of the particulars given in this Paper, which is accompanied by several maps and diagrams, from which a selection has been made, and from which Plate 12, and the Fig. in the text, have been prepared.

APPENDIXES.

I.—LEVELS OF SOME OF THE LOWLANDS DRAINING THROUGH THE TRENT AND IN THE FENLAND, WITH DISTANCES FROM, AND LOW-WATER LEVELS IN, THEIR OUTFALLS.

The land levels in the following Table are taken from the values given on the 6-inch maps of the Ordnance Survey. The date of surveying is in no case less recent than 1880.

Locality.	Lowest Level on Ordnance Survey.	Outfall and Level of L.W.O.S.T.	Total Fall.	Distance to Outfall.	Fall per Mile.
			Feet.	Miles.	Inches.
<i>Trent</i> —Misterton Carr . . .	107·3	The Humber 90·5	16·8	33	5·02
Near South Level Engine . . .	103·5		13·0	27	4·44
Between Trent and Isle of Axholme . . .	104·6		14·1	24	5·55
East of Trent, near Keadby . . .	104·1		13·6	20	6·36
<i>Witham</i> —Nocton Fen . . .	106·2		16·1	29	5·42
Potter Hanworth Fen . . .	106·1	Clay Hole 90·1	16·0	29	5·38
East Fen . . .	100·6		10·5	15	6·00
<i>Welland</i> —Deeping Fen . . .	104·8	Wisbeach Eye 91·3	14·7	22	5·95
<i>Nene</i> —Near Cross Guns . . .	103·0		11·7	24	4·35
Waldersea . . .	102·4	Lynn Roads 91·3	11·1	20	4·86
<i>Ouse</i> —Fareef Fen . . .	102·5		11·2	43	2·29
Whittlesea Mere . . .	98·2		6·9	45	1·04
Between Twenty Foot and Nene . . .	101·8		10·5	35	2·57
Binnimoor Fen . . .	100·0		8·7	30	2·29
March West Fen . . .	100·4		9·1	35	2·09
Glass Moor . . .	99·8		8·5	42	1·57
Middle Moor . . .	100·8		9·5	44	1·77
Ranson Moor . . .	100·9		9·6	37	2·14
Ramsey Hollow . . .	101·0		9·7	42	1·91
Tick Fen . . .	101·6		10·3	41	2·14
Littleport and Downham District . . .	100·6		9·3	30	2·52
Waterbeach Fen . . .	104·7		13·4	45	2·77
Swaffham Fen . . .	103·2		11·9	46	2·32
Burwell Fen . . .	104·0		12·7	46	2·53
Soham Mere . . .	101·7		10·4	44	2·02
Mildenhall Fen . . .	105·0		13·7	41	3·13
Middle Fen . . .	101·5		10·2	39	2·22
Padnal Fen . . .	105·1		13·8	37	3·50
Burnt Fen . . .	100·5		9·2	39	1·91
Feltwell Fen . . .	102·0		10·7	32	2·89
Hockwold Fen . . .	105·0		13·7	36	3·57
Methwold Severals . . .	106·0		14·7	30	4·68
Bardolph Fen . . .	98·6		7·3	22	2·35
Magdalen Fen . . .	97·2		5·9	19	1·83
Marshland Fen . . .	98·4		7·1	20	2·46

The lines of levels generally follow either roads, banks, droves, or drain sides, and in very few cases can a level be found in the middle of a field. As the roads have been raised, the levels on them cannot be taken to represent those of the land. The levels following banks are sometimes given at the foot of the bank; but, as this has often been disturbed (either raised or lowered), the levels on it are best excluded. The fen droves may safely be taken as the ordinary level of the land, except of course where they have been metalled and turned into ordinary roads. By the small drains dividing fields they may be used with confidence, as the fields are cultivated close up to the drains, and the material thrown out is generally ploughed in and so spread about. The levels by the large engine drains have not been used. The lowest level to be found in each district is given, as it is by it that the water must be regulated.

As there is often an area of 1,000 acres or more on which no levels are given in the maps, those in the Table will probably in most cases be somewhat above the lowest in the district. The distance to the outfall is measured along the present river course.

In calculating the fall which might be obtained, a subtraction of 3 feet is made from the land level, to give the level at which the water must be kept in the Fen.

The low-water levels of spring-tides in Clay Hole and Lynn Roads are from observations taken by Mr. W. H. Wheeler, M. Inst. C.E.; that in the Humber being from observations taken by Mr. A. Atkinson, Assoc. M. Inst. C.E., at Ferriby Sluice; the water-level in Wisbeach Eye is taken as the same as in Lynn Roads. The levels are reduced to a datum 100 feet below Ordnance Datum.

II.—EFFECTIVE HP. REQUIRED TO DISCHARGE $\frac{1}{4}$ INCH OF RAIN IN TWENTY-FOUR HOURS FROM DIFFERENT AREAS AT DIFFERENT LIFTS.

	1 Foot.	2 Feet.	3 Feet.	4 Feet.	5 Feet.	7 Feet.	9 Feet.	10 Feet.	15 Feet.
Acres.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.
100	0·12	0·24	0·36	0·48	0·60	0·83	1·07	1·19	1·79
200	0·24	0·48	0·72	0·95	1·19	1·67	2·15	2·38	3·58
300	0·36	0·72	1·07	1·43	1·79	2·50	3·12	3·58	5·36
400	0·48	0·95	1·43	1·91	2·38	3·40	4·29	4·77	7·15
500	0·60	1·19	1·79	2·38	2·98	4·17	5·36	5·96	8·94
700	0·83	1·67	2·50	3·34	4·17	5·84	7·51	8·34	11·52
900	1·07	2·15	3·12	4·29	5·36	7·51	9·66	10·73	16·09
1,000	1·19	2·38	3·58	4·77	5·96	8·34	10·73	11·92	17·88
5,000	5·96	11·92	17·88	23·84	29·80	41·72	53·64	59·60	89·40
10,000	11·92	23·84	35·76	47·68	59·60	83·44	107·28	119·20	178·80
20,000	23·98	47·68	71·52	95·36	119·20	166·88	214·56	238·40	357·60
30,000	35·76	71·52	106·28	143·04	178·80	250·32	321·84	357·60	536·40

MIDDLE FEN DRAINAGE ENGINE AND CENTRIFUGAL PUMP.