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BAZALGETTE

ON THE

MAIN DRAINAGE OF LONDON.

1865.

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AND THE INTERCEPTION OF THE SEWAGE FROM THE RIVER THAMES.

BY

Sir JOSEPH WILLIAM BAZALGETTE, M. Inst. C.E.

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EDITED BY

JAMES FORREST, Assoc. Inst. C.E.,

SECRETARY.

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in the Chair.

No. 1,125.—"On the Main Drainage of London, and the Interception of the Sewage from the River Thames." By JOSEPH WILLIAM BAZALGETTE, M. Inst. C.E.

THE majority of the inhabitants of cities and towns are frequently unconscious of the magnitude, intricacy, and extent of the underground works, which have been designed and constructed at great cost, and are necessary for the maintenance of their health and comfort. It is, however, impossible for large numbers of the human species to congregate and live upon a limited space, without provision being made for the rapid removal of the refuse thereby produced. This necessity is perhaps most forcibly illustrated, by the fearful destruction of life from malaria, produced amongst troops suddenly encamped upon ground not previously so prepared for human habitation. The ravages of disease, thus engendered, became a subject of serious alarm amongst the allied troops in the Crimea; and there are many instances of the mortality in armies arising from this cause, having far exceeded the deaths from actual warfare.

Various methods have been, and still are, adopted in different parts of the globe, for obviating the dangers which thus force themselves upon the attention of mankind. The Jews, it is known, kept a furnace called "Gehenna," or "Hell-fire," constantly burning in the Valley of Hinnom, into which the refuse of the city of Jerusalem was daily cast, as well as the dead bodies of criminals; and even the most savage nations are unable entirely to neglect these considerations. The Chinese, sacrificing to a large extent the delicacy and comfort so highly prized by more civilized nations, but with a sound appreciation of the value of town refuse, apply it in the most direct and rude manner to the production of their growing crops. The solid refuse of Paris has also, for many years, been separated and removed for agricultural manure; but the drainage of that city, and of most of the continental towns, has, until of late years, to a large extent flowed over the surface of the streets. The drainage of English towns has in this respect been mostly in advance of those of other countries; and London, even prior to the introduction of the improved system, was probably the best-drained city of the present age. One important feature, which it is not the object of this communication to dwell upon, has however, up to the present time, been altogether neglected—the Utilisation of Sewage for agricultural purposes. This subject is now occupying much of the consideration of scientific men, and of the public generally, and is deserving of special consideration in a separate Paper.

Before proceeding to describe the modern works for the improved drainage of London, a glance at the early history of its sewerage may not be uninteresting. The Minutes of Proceedings of some of the earlier Commissions of Sewers contain many curious entries, showing that the subject of sewerage received the attention of the Legislature from a very early date. Amongst others, a proposal by Sir Christopher Wren for improved drainage, nearly two hundred years ago, is preserved in MS. in the records of the ancient Westminster Commission.

"Saturday, y^e^ 13th April, 1678.

"Proposalls delivered by S^re^ Christopher Wren touching the new street in St. Margaret's, viz.—

"It is proposed, That whereas y^e^ new sewer in Westminster, now proposed to be carryed through George yard to Stories corner, and thence through Long ditch to Sre Rob Pyes sluice, by an uniforme riseing frome y^e^ Thames to the sayd sluice, so as to receive a flush of water from the Mill ditch, by meanes of the sayd sluice, for the scouring and cleansing of the sayd sewer. Now, if the sayd sewer which is already brought to Stories corner by a riseing levell, should be carried with a fall y^e^ other way through Long ditch, and so through Deane's yard, and all along by the Mill ditch, and then be vented into y^e^ Thames, neare y^e^ sluice of the Mill. And if a small branch with a sluice should be brought from the King's canall with His Majesty's allowances. It is conceived this way would be far more advantageous to cleane y^e^ sewer, than y^e^ antient ways of receiving a flush from the Mill pools, and may be done at any ebbe, and the charge will be lesse than y^e^ scouring and wharfeing the Mill poole, because ten times the quantity of water may be afforded from the canall without drawing downe canall above 4 inches, which will be immediately supplyed again at flood, and y^e^ water taking the sewer in the middle and driveing downe two waies to each end of the sewer will more effectually cleanse it.

"That a Draught of a Decree be made according to y^e^ proposalls aforesayd."

"Saturday y^e^ 30th of Nov., 1678.

"Upon readeing a paper intituled, An Estimate of y^e^ Charge of several Works to be done in relation to y^e^ Back Waters in St. Margarett's, Westminster. It is ordered, That the worke therein mentioned, to be done in Brasbyes alley in Gardener's lane, be forthwith done and performed. And that the other particulars in the sayd paper mentioned, be referred to Sir Christopher Wren, who is desired to consider the same and make report what is fitt to be done therein."

Commissioners of Sewers were in those days persons of considerable importance, for on the 4th February, 1663, it was ordered "that y[e] kinges Majestie (Charles II.) beare one halfe of y[e] charge of y[e] carrying away of y[e] rubbish at the sluice by his said Majesties bouling green," and on the 17th April, 1669, "That Francis Crassett, clerk to this Commission, doo attend his Majesties officers concerning the Kinges arreares which are in arreare upon his said Majestie for casting y[e] comon sewers synce y[e] thyme of his Majesties happy restauration," and again in 1768, His Majesty George III. was permitted by an order of Court of the Westminster Commissioners of Sewers, at his own cost, to alter the line of the King's Scholar's Pond Sewer from under Her Majesty the Queen's palace in St. James's Park, and it was—

"Ordered that His Majesty may remove the sewer from under Her Majesty's the Queen's Palace in St. James's Park, by making a new sewer from the north side of this said Palace to the road leading from Buckingham Gate towards Pimlico, at His Majesty's expense if His Majesty so pleases."

Up to about the year 1815, it was penal to discharge sewage, or other offensive matters, into the sewers; cesspools were regarded as the proper receptacles for house drainage, and sewers as the legitimate channels for carrying off the surface waters only. Afterwards it became permissive, and in the year 1847 the first Act was obtained making it compulsory, to drain houses into sewers.

The Fleet Sewer, formerly known as the River of Wells, or the Old Bourne (now called Holborn), was fed by several springs, from which originated the names of many of the populous districts of London, such as Sadler's Well, Bagnigge Well, Lamb's Conduit, Chad's Well, and Clerk's Well or Clerkenwell, which latter derived its name from the parish clerks of the City of London, who used to meet there annually to represent certain parts of Scripture in a theatrical manner, and thither the nobility, the lord mayor and citizens repaired to see the performances.

In 1218, the Fleet supplied the people residing west of Chancery Lane, then called "Foreigners," with water; and in 1307, a mill, the property of the Templars, was removed on the ground that it disturbed the water. The Fleet Sewer was at that time navigated up to Holborn Bridge, and it was not until 1732 that it was, by Act of Parliament, covered in between Holborn Bridge and Fleet Bridge.

The waters from a spring at Tye Bourne and from the Bayswater Brook (now called the Ranelagh Sewer) were also conveyed, in 6-inch leaden pipes, into the neighbouring dwellings; and, in 1730, Queen Caroline fed the Serpentine in Hyde Park with water from the Ranelagh. Of late years, however, the water so polluted the lake that it has been diverted by a new sewer through the Park.

The Ranelagh and the King's Scholars' Pond Sewers, the Fleet Ditch, and other main valley lines were at this time, and for many subsequent years, open brooks, ponded up at various points along their route, so as to form ornamental waters in the pleasure-grounds of the gentry, who lived in what still continued to be the suburbs of the metropolis. The Commissioners of Sewers of those days were wont to make an annual personal inspection of the sewers under their charge, a duty which has of late years been discontinued.

As the population of London increased, the subsoil became thickly studded with cesspools, improved household appliances were introduced, overflow drains from the cesspools to the sewers were constructed, thus the sewers became polluted, and covered brick channels were necessarily substituted for existing open streams.

Prior to the year 1847, the sewers were under the management of eight distinct Commissions, viz., the City, Westminster, Holborn and Finsbury, Tower Hamlets, Poplar and Blackwall, Surrey and Kent, Greenwich, and St. Katharine's Commissions of Sewers. These were independent bodies; each appointed its own officers, and carried out its drainage works, frequently regardless of the effect thereby produced upon the neighbouring districts, through which the sewage flowed. The works were not constructed upon a uniform system; and the sizes, shapes, and levels of the sewers at the boundaries of the different districts were often very variable. Larger sewers were made to discharge into smaller ones; sewers with upright sides and circular crowns and inverts were connected with egg-shaped sewers; and egg-shaped sewers with the narrow part uppermost were connected with similar sewers having the smaller part downwards.

In the year 1847, these eight Commissions of Sewers were superseded by one Commission, termed "The Metropolitan Commission of Sewers," whose members were nominated by the Government. That Commission entertained opposite views respecting the use of sewers to those which had been previously held, and directed its energies mainly to the introduction of pipe-sewers of small dimensions, in lieu of the large brick sewers previously in vogue, to the abolition of cesspools, and to the diversion of all house drainage (by direct communications) into the sewers, making the adoption of the new system of drainage compulsory; so that, within a period of about six years, thirty thousand cesspools were abolished, and all house and street refuse was turned into the river.

Similar systems were, about the same period, to a large extent adopted in the provincial towns, by which means their drainage has been vastly improved, but the rivers and streams of the country have become very generally and seriously polluted.

During the existence of this Commission, the Author first became officially connected with the drainage of London; but, within nine years after its formation, the Metropolitan Commission of Sewers was six times superseded, and six new and differently constituted Commissions were successively appointed. These were however unable, during their limited period of office, to mature and carry out works of any magnitude.

The second of these Commissions was issued in 1849. The Thames at that time was becoming full of sewage; and as several of the Water Companies then obtained their supply from the river at or near London, the public press began to agitate for a remedy for this rapidly-increasing evil. The Commissioners, by advertisement, invited designs for the purification of the river, in answer to which they received one hundred and sixteen different schemes, proposing various methods for the accomplishment of that object, and in the midst of the perplexity of selecting from these designs, and of the public excitement thereby produced, the Commission resigned. The late Mr. Robert Stephenson, Mr. Rendel, and Sir William Cubitt were appointed members of the third Commission, and they undertook the classification and investigation of the merits of these competing plans, and eventually, after much careful consideration, arrived at the conclusion, that whilst the plan of Mr. M'Clean (President Inst. C.E.) was the best, none could be recommended for execution as a whole.

In 1850, Mr. Frank Forster was appointed Chief Engineer of the Commission; under his direction, Messrs. Grant and Cresy commenced the preparation of a plan for the interception of the sewage of the area south of the Thames, and Mr. Haywood, the Engineer of the City Commissioners of Sewers, assisted Mr. Forster in the preparation of a similar plan for the districts on the North side.

In 1851, the fourth Commission was appointed, when one of its members prepared and advocated a plan of his own, in opposition to the plan of Mr. Forster. Mr. Forster's health giving way under the excitement of protracted opposition, he resigned his position, and shortly afterwards died.

In 1852, the fifth Commission was issued, and the Author succeeded Mr. Forster as Chief Engineer. Fresh plans for intercepting the sewage of the metropolis still continued to be laid before the Commission, and were from time to time examined and reported on, without any practical result. In 1854, the Author was directed to prepare a scheme of intercepting sewers, intended to effect the improved Main Drainage of London, and Mr. Haywood was associated with him for the northern portion.

The late Mr. Robert Stephenson and Sir William Cubitt afterwards devoted much time and attention to the consideration of the plan so prepared, and eventually recommended its adoption.

In February, 1854, Mr. Cubitt reported that—

> "After a very careful examination of the reports and plans, and the elaborate set of sections and details which they (Messrs. Bazalgette and Haywood) have produced, together with the estimate founded thereon, that the whole are worthy of every attention as regards the capacities and inclinations of the various intercepting drains, in relation to the quantities of water they have to carry and discharge. The matter is, in fact, so clearly and minutely set forth in report, plans, and sections, that the Engineers have laid themselves entirely open to detection by any persons who understand practical engineering, inasmuch as, in their present state, the documents would enable such a person to make a correct estimate of the amount at which any portion of the works might be contracted for; a fact highly creditable to the Engineers."

The sixth Commission, formed in 1855, continued to discuss the subject, without coming to any practical result, up to the time of its dissolution, and of the formation of the present "Metropolitan Board of Works," in 1856.

But it was not alone the anomalies of the old Commissions, and the necessity for providing for the great increase in drainage matter caused by modern improvements, which compelled the adoption of a general system of Main Drainage. The metropolis had suffered severely in the cholera visitation of 1831-2, again in 1848-9, and lastly in 1853-4. In 1849 the deaths were 18,036, and in 1854 nearly 20,000; and although great differences of opinion existed, and continue to exist, as to the causes of the disease, yet an inspection of the houses in which deaths occurred was sufficient to show that, however occult might be the connection between death and defective drainage, the places formerly most favourable to the spread of disease became quite free from it, when afterwards properly drained.

Acting on the indications afforded by the Registrar-General's return, the Commissioners of Sewers endeavoured to afford an outlet into a good sewer for every suspected locality; but they speedily found that a limit had been put to their operations, by the carelessness and cupidity of preceding generations. Builders had in many cases, especially on the south side of the Thames, availed themselves of the comparative cheapness of the land, and placed their houses in spots not only sewerless, but where no outlets for sewers existed. In designing a system of Main Drainage, these points had to be kept in view,—to provide ample means for the discharge of the large and increasing water supply consequent on the universal adoption of closets, and of the ordinary rainfall and surface drainage at all times, except during extraordinary storms, and to afford to the low-lying districts a sufficiently deep outfall to allow of every house being effectually relieved of its fluid refuse.

For centuries there had existed Sewers Commissions appointed by the Government, and irresponsible to the ratepayers, upon whom they levied rates, and for whose benefit they expended them, and the substitution of the Metropolitan Board of Works was the first introduction of the system of local self-government. Under this Act London is divided into thirty-nine districts. The City of London and the larger parishes, such as Marylebone and Lambeth, each form one district, and minor parishes are united to form other districts. The ratepayers of each parish, or district, elect from among themselves a prescribed number of representatives, to form a board, who manage the local drainage, paving, lighting, and other improvements, and these district boards select from their body one or more members (proportionate to the population and extent of the district) to form the Metropolitan Board, which consists of forty-five members, presided over by a Chairman, and has control over the Main Sewers, the Thames Embankment, all new streets, and metropolitan improvements, and makes bye-laws for the direction and control of the different vestries and district boards.

The Author, having been appointed Engineer to the Metropolitan Board, was again instructed to prepare a plan for the drainage of the metropolis, and, when completed, it was approved and adopted by the Board. Her Majesty's First Commissioner of Works, however, having a veto under the Act constituting the Board, refused, upon a technical point, to sanction this plan. His decision was resisted by the Board, and the difficulty was ultimately removed. He had, however, referred the plan for examination to a Commission of Engineers named by him, which Commission substituted and recommended a design of their own, in lieu of that approved by the Board. The Royal Commissioners' plan was, in its turn, submitted by the Metropolitan Board of Works to Mr. Bidder, Mr. Hawksley, and the Author, upon whose Report the Board's plan was, after much discussion and delay, eventually adopted, and the works were commenced in 1859. It was through the influence of Lord John Manners, who afterwards became the First Commissioner of Works, that the Board was left free to carry out their system of Main Drainage.

The works involved in that design are now practically completed and in operation. They are illustrated more particularly by the contract drawings and specifications herewith presented to the Institution, and a description of the works forms the more immediate subject of this Paper.

The objects sought to be attained in the execution of the Main Drainage works were the interception of the sewage (as far as practicable by gravitation), together with so much of the rainfall mixed with it as could be reasonably dealt with, so as to divert it from the river near London; the substitution of a constant, instead of an intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulations of deposit; and the provision of deep and improved outfalls, for the extension of sewerage into districts previously, for want of such outfalls, imperfectly drained.

Having these objects in view, it is easier and more economical to originate a new and complete system of drainage, than to adapt existing and defective sewers to a uniform and more perfect system.

According to the system which it was sought to improve, the London Main Sewers fell into the valley of the Thames, and most of them, passing under the low grounds on the margin of the river before they reached it, discharged their contents into that river at or about the level, and at the time of low water only. As the tide rose it closed the outlets, and ponded back the sewage flowing from the high grounds; this accumulated in the low-lying portions of the sewers, where it remained stagnant in many cases for eighteen out of every twenty-four hours. During that period the heavier ingredients were deposited, and from day to day accumulated in the sewers; besides which, in times of heavy and long-continued rains, and more particularly when these occurred at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage, which then rose through the house drains and flooded the basements of the houses.

The effect upon the Thames, of thus discharging the sewage into it at the time of low water, was most injurious, because not only was it carried by the rising tide up the river, to be brought back to London by the following ebb tide, there to mix with each day's fresh supply,—the process of many days' accumulation towards the sea being almost imperceptible,—but the volume of the pure water in the river, being at that time at its minimum, rendered it quite incapable of diluting and disinfecting such vast masses of sewage.

In the system now adopted, it has been sought to remove these evils by the construction of new lines of sewers, laid at right angles to the existing sewers, and a little below their levels, so as to intercept their contents, and convey them to an outfall 14 miles below London Bridge. As large a proportion of the sewage as practicable is by this means carried away by gravitation, and for the remainder a constant discharge is effected by pumping. At the outlets, the sewage is delivered into reservoirs situate on the banks of the Thames, and placed at such a level as will enable them to discharge into the river at or about the time of high water. By this arrangement, the sewage is not only at once diluted by the large volume of water in the Thames at high water, but is also carried by the ebb tide to a point in the river, 26 miles below London Bridge, and its return by the following flood tide, within the metropolitan area, is effectually prevented.

At the threshold of any inquiry into this subject, the following important points required to be solved:—

1st. At what point and state of the tide can the sewage be discharged into the river so as not to return within the more densely inhabited portions of the metropolis?

2nd. What is the minimum fall which should be given to the intercepting sewers?

3rd. What is the quantity of sewage to be intercepted, and does it pass off in a uniform flow at all hours of the day and night, or in what manner?

4th. Is the rainfall to be mixed with the sewage, in what manner and quantities does it flow into the sewers, and is it also to be carried off in the intercepting sewers, or how is it to be provided for?

5th. Having regard to all these points, how are the sizes of the intercepting and main drainage sewers to be determined?

6th. What descriptions of pumping engines and of pumps are best suited for lifting the sewage of London at the pumping stations?

So comprehensive a subject, involving not only the above, but many other important topics, cannot be fully considered within the limits of an ordinary Paper, in which these questions can only be briefly touched upon.

The position of the outfalls and the time of discharge into the river were arrived at in the mode described in the following extract from the Report of the late Mr. Robert Stephenson and Sir William Cubitt, dated the 11th December 1854; wherein they give a brief summary of a series of experiments made by the late Mr. Frank Forster, and subsequently repeated by Captain Burstal, R.N., and the Author, upon this subject—

"On the 13th of July, 1851, a float was put into the centre of the river opposite Barking Creek two hours after high water. This time was chosen, because it was found that sewage discharged into the river two hours before high water arrived at about the same point above Barking Creek as sewage discharged two hours after high water did by the next flood tide. At low water the float reached $11\frac{3}{4}$ miles below that point, and returned with the next flood tide to 1 mile above it, having gone $12\frac{3}{4}$ miles that flood, it being then the period of spring tides.

"As the neaps came on, the float continued to work lower down at each succeeding high water, and by the 24th of July it was 13 miles below Barking Creek at high water, having gone down the river 14 miles during the falling off of spring tides to neap tides. As the floods again became stronger, it worked up the river each succeeding tide until the 29th July, when it again came within 5 miles below Barking Creek at high water, having worked up the river 9 miles from high water neap tides to high water spring tides, the excess of the ebbs over the floods being only 5 miles in fourteen days.

"Another experiment was tried at the same place on the 6th of August, 1851, it being then lowest neaps, and the float being put down two hours after high water. It worked up each succeeding high water till top springs on the 12th of August, when it reached 6¼ miles above Barking Creek at high water. The float then again worked down the river, till the 20th of August, 9½ miles below Barking Creek, being a distance of 16 miles during the falling off of spring tides to neap tides. The excess of ebbs over the floods would in this case have been about 7 miles in fourteen days. The wind and other causes would vary the result, but it may be roughly assumed, that a substance in suspension works up the river about 1 mile a day at each high water as the springs strengthen, and down the river 2 miles a day as they fall off."

The main object was of course to determine, how near to London the sewage could be discharged into the river, at or near high water, without finding its way back again to the inhabited parts of the town. The experiments proved, that it was essential to go as far as Barking Creek; and also, as regards the level of the discharge, they demonstrated that it should take place at or as near high water as practicable.

Now, although it is desirable to fix the place of discharge as far below the metropolis as possible, it will be found that a practical limit to this point is imposed on the north side of the river, by the advantages gained from a discharge by gravitation, and by the necessity of maintaining a sufficient fall in the sewers; and on the south side, in order to preserve as a safety outlet a discharge into the river at low water by gravitation, in case of accident to the pumps, as well as during excessive floods.

As regards the time of discharge, it is demonstrated by the same series of experiments that—

"The delivery of the sewage at high water into the river at any point is equivalent to its discharge at low water at a point 12 miles lower down the river, therefore the construction of 12 miles of sewer is saved by discharging the sewage at high instead of low water."

As to the velocity of flow and the minimum fall, though it is necessary to economize the fall of the sewers in order to save pumping, yet a sufficient velocity of flow to prevent deposit must at the same time be maintained, and the question—What is a sufficient flow? must be determined.

Upon this point Mr. Wicksteed, in his Report upon the Drainage of Leicester (p. 19), states—

"From experiments made by me with great care, I find that with a bottom velocity of 16 inches per second only (or 0·90 mile per hour) heavy pieces of brick, stone, &c., will be removed, and that with a velocity of 21¾ inches (or 1·24 mile per hour), even iron borings and heavy slag will be removed. The above minimum velocity will therefore be sufficient."

Mr. Beardmore, in his work on Hydraulics, states (p. 8) that "a velocity of 150 feet per minute (or 1¾ mile per hour) will generally prevent deposits in pipes and sewers."

Mr. John Phillips states (see First Report of Sanitary Commission, 1847, p. 177),—

"From observation and experiment, I find that it requires a constant velocity of current to be running through the sewers equal to about 2½ feet per second, or about 1¾ mile per hour, to prevent the soil from depositing within them."

Professor Robison, in his "Theory of Rivers," states, at page 465, that—

"We learn from observation, that a velocity of 3 inches per second at the bottom will just begin to work up fine clay fit for pottery, and however firm and compact it may be, it will tear up."

"A velocity of 6 inches will lift fine sand, 8 inches will lift sand as coarse as linseed, 12 inches will sweep along fine gravel, 24 inches will roll along rounded pebbles an inch diameter, and it requires 3 feet per second at the bottom to sweep along shivery angular stones of the size of an egg."

It is difficult to lay down any general rule upon this point, because the conditions of sewers, as to the quantity of deposit passing into them, and the ordinary volume of the sewage flowing through them, vary considerably. But the Author does not hesitate to rely upon these opinions, confirmed as they are by his own observations and experience, which lead him to regard a mean velocity of 1½ mile per hour, in a properly protected main sewer, when running half full, as sufficient, more especially when the contents have previously passed through a pumping station.

Having thus determined the minimum velocity, it becomes necessary to ascertain the quantity of sewage to be carried off, before the fall requisite to produce that velocity can be estimated. This quantity varies but little from the water supply with which a given population is provided; for that portion which is absorbed and evaporated is compensated for by the dry weather underground leakage into the sewers. The water supply to various parts of London in 1856 varied from 20 gallons to 25 gallons per head per diem; but a more liberal supply was contemplated, and that supply was likely to be further augmented, by an increase in the population in certain districts not then wholly built upon. It was ascertained that a district of average density of population, when wholly built upon, contained 30,000 people to the square mile, so that in districts containing that, or more than that number of people to the square mile, the actual numbers were ascertained and provided for; but in districts where the population was below that number, provision has been made for an increase of population up to 30,000 people to the square mile, except over the outlying districts, where provision has been made for a population of only 20,000 to the square mile.

An improved water supply, equal to 5 cubic feet, or 31¼ gallons, per head for such contemplated increased population, has moreover been anticipated. The effect upon the Thames of the diversion from its channel of water for the supply, not only of London but also of other towns, appears already to have attracted the notice of the Legislature.

Experience has shown, that sewage is not discharged into the sewers at a uniform rate throughout the twenty-four hours, nor even throughout the day. Mr. Lovick, the Assistant Engineer, made some careful observations on this subject for the late Metropolitan Commission of Sewers. The habits of the population in various parts of London are indicated by the flow of sewage through the sewers; the maximum flow in the more fashionable districts of the West end being two or three hours later than from the East end. Taking, as before, a liberal margin beyond the results of actual measurements, provision has been made for one-half of the sewage to flow off within six hours of the day; and thus the maximum quantity of sewage, likely hereafter to enter the sewers at various parts of the metropolis, has been arrived at.

How to dispose of the rainfall is a question of considerable difficulty, and has given rise to much diversity of opinion. This arises from the fact that, whilst it is in itself harmless, and even advantageous, to the river, it sometimes falls suddenly in large quantities. These considerations have induced theorists to advocate, that the rainfall should not be allowed to flow off with the sewage, but should be dealt with by a separate system of sewers. This theory is, however, most impracticable. It would involve a double set of drains to every house, and the construction and maintenance of a second series of sewers to every street. Applied to London, it would involve the re-draining of every house and every street in the metropolis; and, according to a moderate estimate, it would lead to an expenditure of from ten to twelve millions of money, while the interference with private property would alone render such a proposition intolerable.

Careful observations of the quantity of rain falling on the metropolis within short periods have been made by the Author for many years. Taking an average of several years, it has been ascertained that there are about one hundred and fifty-five days per annum upon which rain falls; of these there are only about twenty-five upon which the quantity amounts to ¼ of an inch in depth in twenty-four hours, or the 1-100th part of an inch per hour, if spread over an entire day. Of such rainfalls a large proportion is evaporated or absorbed, and either does not pass through the sewers, or does not reach them until long after the rain has ceased. In the Report of Mr. Bidder, Mr. Hawksley, and the Author, in 1858, on this subject, it is stated that continuous observations, and as far as practicable protected from disturbing influences, had been taken at the close of the previous year, and that these observations, which were recorded in the Appendix to the above Report, had enabled them to arrive at some reliable conclusions, and that,—

"The result of these observations distinctly establishes the fact, that the quantity of rain which flowed off by the sewers was, in all cases, much less than the quantity which fell on the ground; and although the variations of atmospheric phenomena are far too great to allow any philosophical proportions to be established between the rainfall and the sewer flow, yet we feel warranted in concluding, as a rule of averages, that ¼ of an inch of rainfall will not contribute more than ⅛ of an inch to the sewers, nor a fall of $\frac{4}{10}$ of an inch more than ¼ of an inch. Indeed, we have recently observed rainfalls of very sensible amounts failing to contribute any distinguishable quantity to the sewers."

But there are, in almost every year, exceptional cases of heavy and violent rain-storms, and these have measured 1 inch, and sometimes even 2 inches, in an hour. A quantity equal to the 1-100th part of an inch of rain in an hour, or ¼ of an inch in twenty-four hours, running into the sewers, would occupy as much space as the maximum prospective flow of sewage provided for; so that, if that quantity of rain were included in the intercepting sewers, they would, during the six hours of maximum flow, be filled with an equal volume of sewage, and during the remaining eighteen hours additional space would be reserved for a larger quantity of rain. Taking this circumstance into consideration, and allowing for the abstraction due to evaporation and absorption, it is probable that if the sewers were made capable of carrying off a volume equal to a rainfall of ¼ of an inch per day, during the six hours of the maximum flow, there would not be more than twelve days in a year on which the sewers would be overcharged, and then only for short periods during such days. But exceptional rain-storms must be provided for, however rare their occurrence, or they would deluge the property on which they fell. As it would not have been wise, or practicable, to have increased the sizes of the intercepting sewers much beyond their present dimensions, in order to carry off rare and excessive thunderstorms, overflow weirs, to act as safety-valves in times of storm, have been constructed at the junctions of the intercepting sewers with the main valley lines: on such occasions the surplus waters will be largely diluted, and, after the intercepting sewers are filled, will flow over the weirs, and through their original channels into the Thames.

Having thus determined the quantities of sewage and rainfall to be carried off, and the rate of declivity of the sewer required for the necessary velocity of flow, the sizes of the intercepting sewers were readily determined by the formulæ of Prony, Eytelwein, and Du Buat; and the sizes of the drainage sewers by the useful formula of Mr. Hawksley, which, with some modifications, may be applied to a variety of conditions and circumstances, and with respect to which the Author would again quote from the Report of the late Mr. R. Stephenson and Sir William Cubitt of the 11th December, 1854, in which it is said:—

"No part of Engineering science has been more industriously investigated than the laws that govern the flow of water in pipes and open channels; and it is probably not too much to say, that the formulæ which represent these laws rank amongst the most truthful that the professional man possesses. They have been the subject of laborious experimental investigation of the most elaborate character, and their results have been tested by the practical man under every variety of conditions, without their truth being impugned in the slightest degree. The principles upon which they are founded have been sanctioned and adopted by Prony, Eytelwein, Du Buat, and others; and it is to them that we are indebted, in a great measure, for the simple practical form which they present. Our own Engineers have modified them to suit particular circumstances, and given them more extensive usefulness. Mr. Hawksley, amongst others, has especially contributed to render the principles which they embrace applicable to almost every variety of condition which the complete drainage of large towns involves; and we shall have occasion, almost immediately, to adduce some instances within the metropolis, where the facts confirm theoretical deductions in a very remarkable manner, and lead irresistibly to the conclusion that they may be implicity depended on."

With respect to the description of pumping engines and pumps to be employed, various opinions existed as to the comparative advantages of Cornish or rotative engines, and as to the respective merits of centrifugal and screw pumps, chain pumps, lifting bucket wheels, flash wheels, and of every variety of suction or plunger pump and pump valve for raising the metropolitan sewage. In 1859, numerous competing designs, involving all these principles, were reported upon by Messrs. Stephenson, Field, Penn, Hawksley, Bidder, and the Author; and the pumping engines and pumps subsequently designed for, and adopted by, the Metropolitan Board of Works are based upon the recommendations contained in that Report. The engines are condensing double-acting rotative beam engines, and the pumps are plunger or ram pumps, the sewage being discharged from the pumps through a series of hanging valves.

The contractors for the engines at Crossness and at Abbey Mills guarantee that the engines shall, when working, raise 80 million lbs. one foot high, with 1 cwt. of Welsh coal.

A primary object sought to be attained in this scheme was the removal of as much of the sewage as practicable by gravitation, so as to reduce the amount of pumping to a minimum. To effect this, three lines of sewers have been constructed on each side of the river, termed respectively the High Level, the Middle Level, and the Low Level. The High and the Middle Level Sewers discharge by gravitation, and the Low Level Sewers discharge only by the aid of pumping. The three lines of sewers north of the Thames converge and unite at Abbey Mills, east of London, where the contents of the Low Level will be pumped into the Upper Level Sewer, and their aggregate stream will flow through the Northern Outfall Sewer, which is carried on a concrete embankment across the marshes to Barking Creek, and there discharges into the river by gravitation.

On the South side, the three intercepting lines unite at Deptford Creek, and the contents of the Low Level Sewer are there pumped to the Upper Level, and the united streams of all three flow in one channel through Woolwich to Crossness Point in Erith Marshes. Here the full volume of sewage can flow into the Thames at low water, but will ordinarily be raised by pumping into the reservoir.

With respect to the form of the sewers, as the intercepting sewers carry off only the 1-100th part of an inch of rain in an hour, and the volume of sewage passing through them is at all times considerable, the flow through these sewers is more uniform than in drainage sewers constructed to carry off heavy rain-storms. The form, therefore, generally adopted for the intercepting sewers is circular, as combining the greatest strength and capacity with the smallest amount of brickwork and the least cost. In the minor branches, for district drainage, the egg shape, with the narrow part downwards, is preferable; because the dry weather flow of the sewage being small, the greatest hydraulic mean depth, and consequently the greatest velocity of flow and scouring power, is obtained by that section in the bottom at the period when it is most required, and the broader section at the upper part affords room for the passage of the storm-waters, as also for the workmen engaged in repairing and cleansing.

Having thus briefly glanced at the early history of the drainage of London, and the circumstances which led to the adoption of the main intercepting scheme, and a few of the considerations and general principles upon which that scheme is based, a more detailed description of the works will now be given, as well as of some of the peculiarities or difficulties met with during their construction.

The North Side of the Thames.

The High Level Sewer was constructed under one contract. It commences by a junction with the Fleet Sewer, at the foot of Hampstead Hill, and passes along Gordon House Lane, and across the Highgate Road. It is carried through Tufnell Park Road, Holloway Road, under the Great Northern Railway, and the New River to High Street, Stoke Newington, at Abney Park Cemetery. It then passes under the Rectory and Amhurst roads to Church Street, Hackney; under the North London Railway, through Victoria Park, and under Sir George Duckett's Canal to a junction with the Middle Level Sewer. Up to this point it is a drainage sewer, that is to say, it is a substitute for the open Fleet and Hackney Brook main sewers, which have since been filled in and abandoned; and it has been constructed of such dimensions, as to be capable of carrying off the largest and most sudden falls of rain. It is about 7 miles long, drains an area of about 10 square miles, and intercepts the sewage of Hampstead, part of Kentish Town, Highgate, Hackney, Clapton, Stoke Newington, and Holloway. A portion of the district adjoining the Hackney Marshes is so low, that it was necessary to drain it through a branch passing into the Low Level Sewer. The form of the High Level Sewer is mostly circular, and it varies in size from 4 feet in diameter to 9 feet 6 inches by 12 feet; its fall is rapid, ranging at the upper end from 1 in 71 to 1 in 376, and from 4 feet to 5 feet per mile at the lower end.

It is constructed of stock brickwork, varying in thickness from 9 inches to 2 feet 3 inches, and the invert is lined with Staffordshire blue bricks, in order to withstand the scour arising from the rapid fall. One tunnel, from Maiden Lane towards Hampstead, is about ½ a mile long, and great care was necessary in tunnelling under the New River, its channel being on an embankment where it intersects the line of sewer; also under the Great Northern Railway, at a place where its embankment is 30 feet high, the sewer being 7 feet 6 inches in diameter, and the brickwork 14 inches in thickness.

Much house property was successfully tunnelled under at Hackney. One house, adjoining the railway station, was underpinned and placed upon iron girders, and the sewer, being there 9 feet 3 inches in diameter, was carried through the cellar without further injury to the house. The sewer is carried close under the bottom of Sir George Duckett's Canal, the distance between the soffit of the arch of the sewer and the water in the canal being only 24 inches. The bottom of the canal and the top of the sewer are here formed of iron girders and plates, with a thin coating of puddle, and no leakage from the canal has taken place. This was the first portion of the Main Drainage works executed, and it was completed in the year 1854. The whole of the High Level Sewer, including the Penstock Chamber, was completed in May, 1861, and has been in full operation since that date.

The Penstock Chamber, which is formed at the junction of the High and the Middle Level Sewers at Old Ford, Bow, is provided with five large iron penstocks worked by machinery, by which the sewage can be diverted at will either into the two lower channels formed for the discharge of the storm-waters into the River Lea, or into the two upper channels constructed over that river, and forming the commencement of the Northern Outfall Sewer. As a rule the lower channels will be closed, and the sewage will flow through the two upper channels to Barking Creek; but in times of heavy rain, as soon as the waters have risen to the top of the upper channels, the surplus will flow over five weirs, constructed in the chamber, into the lower channels, and be discharged by them into the Lea. In case of any sudden accident to the intercepting sewers, the whole of the sewage could, by raising the lower penstock, be diverted in a few minutes into the Lea.

The penstock and weir chamber is a novel arrangement, which has proved to be simple and satisfactory in its operation, and it places three-fourths of the Northern sewage completely under command. It is built in brickwork, is about 150 feet in length, 40 feet in breadth, and, in places, 30 feet in height.

The principal difficulties to be overcome during the construction of this line of sewer arose from the continued combinations and strikes, which at that time prevailed amongst the workmen, in various parts of England. It is to be hoped that the good sense and good feeling of both the parties concerned will find means for avoiding a recurrence of these public calamities. It is curious to notice, that the injury thus produced was considered so serious in the reign of Edward VI. as to induce the Legislature to pass a statute for the repression of strikes and combinations amongst the workmen. The statute provided that, upon conviction, the offenders should be punished by means not quite consistent with the policy of the present age, viz.—by the infliction not only of fine or imprisonment, but also, for repeated offences, by the punishment of the pillory, having an ear cut off, and being rendered infamous and incapable of giving evidence upon oath.

A long-continued wet season prevented the manufacture of bricks, while the demand for them was greatly increased by the formation of several metropolitan railways and other public works at the same period; the prices of building materials and labour rose therefore considerably, and the combination of these untoward circumstances rendered this an unprofitable work for the contractor.

The Middle Level Sewer was formed under one contract, and is carried as near to the Thames as the contour of the ground will permit, with the object of intercepting as much sewage as possible by gravitation, and of reducing to a minimum the low level area which is dependent upon pumping. The area intercepted by this sewer is 17½ square miles in extent, and is densely inhabited. The sewer commences near the Harrow Road at Kensal Green, passes under the Paddington Canal into the Uxbridge Road at Notting Hill, along Oxford Street, Hart Street, Liquorpond Street, and across Clerkenwell Green; thence by way of Old Street Road to High Street, Shoreditch, along Church Street, Bethnal Green Road, and Green Street, under the Regent's Canal and the North London Railway, to a junction with the High Level Sewer at the Penstock Chamber at Bow. In order to enlarge the area drained by gravitation, a branch, 4 feet by 2 feet 8 inches, with a fall of 4 feet per mile, is carried along Piccadilly, passes through Leicester Square and Lincoln's Inn Fields to the main line at King's Road, Gray's Inn Road. The length of the main line is about 9½ miles, and of the Piccadilly Branch 2 miles, besides which there are minor branches and feeders. The fall of the Main Sewer varies from 17½ feet per mile at the upper end, by a gradual reduction, to 2 feet per mile at the lower end.

The sizes vary from 4 feet 6 inches by 3 feet, to 10 feet 6 inches in diameter, and lastly to 9 feet 6 inches by 12 feet at the outlet. About 4 miles of the main line, and the whole of the Piccadilly Branch, were constructed by tunnelling under the streets, at depths varying from 20 feet to 60 feet. This sewer is formed mostly in the London clay; to the east of Shoreditch it is constructed through gravel, and during the execution of the works under the Regent's Canal, the water burst into the sewer, fortunately giving sufficient warning to prevent any loss of life. The sewer was afterwards constructed under the canal, first by enclosing one-half of the width of the tunnel at a time within a coffer-dam, and then by open cutting.

The Middle Level Sever is carried over the Metropolitan Railway by a wrought-iron aqueduct of 150 feet span, weighing 240 tons; the depth of construction between the under side of the aqueduct and the inverts of the double line of sewers being only 2½ inches. As the traffic of the railway could not be stopped during the construction of the aqueduct, which is only a few inches above the engine chimneys, the structure was built upon a stage, at a height of 5 feet above its intended ultimate level, and was afterwards lowered into place by means of hydraulic rams. This stage was necessarily of great strength and was carefully constructed; the sewers being formed by wrought-iron plates riveted together.

The Middle Level Sewer is provided with weirs, or storm-overflows, at its various junctions with all the main valley lines. It has recently been completed, and is now in active operation.

The Low Level Sewer, besides intercepting the sewage from the low level area, which contains 11 square miles, is also the main outlet for a district of about 14½ square miles, forming the western suburb of London, which is so low, that its sewage has to be lifted at Chelsea a height of 17½ feet, into the upper end of the Low Level Sewer. This sewer commences at the Grosvenor Canal, Pimlico, and passes along Lupus Street and Bessborough Street, to and along the river side from Vauxhall Bridge. From Westminster Bridge to Blackfriars it is being formed as part of the Thames Embankment; and thence it will pass under a portion of the new street to the Mansion House, and will probably take the line of the Inner Circle Railway to Tower Hill. From Tower Hill it is being formed mostly by tunnelling along Mint Street, Cable Street, Back Road, Commercial Road, and under the Limehouse Cut and Bow Common. It is now being tunnelled under the River Lea, on its route to the Abbey Mills pumping station, where its contents will be raised 36 feet by steam power. It has two branches:—one from Homerton, and the other from the Isle of Dogs. This island was formerly a dismal marsh, and received its name from the circumstance of the king's hounds having been kept there, when the Court was at Greenwich. It is now the site of extensive factories and works, and is largely populated by artisans and workmen. Its drainage can only be perfected by the aid of pumping, the beneficial effect of which was so well described by the late Mr. R. Stephenson and Sir W. Cubitt, when they compared it to the lifting of the whole district out of a hollow, on to high ground above the level of the river. The length of the main line is 8¼ miles, and its branches are about 4 miles in length. Its size varies from 6 feet 9 inches to 10 feet 3 inches in diameter, its inclination ranges from 2 feet to 3 feet per mile, and it is provided with storm-overflows into the river.

The Western Division includes Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton. It was originally intended to deodorise, or utilise, the sewage of this district in its own neighbourhood, rather than to incur the heavy cost of carrying it to Barking, and lifting it twice on its route to that place. But strong objections to this having been raised, the latter and more costly plan has since been adopted, and now forms part of the Low Level system of drainage.

In this district a new system of main sewers has been laid, the sewers being conveyed into one channel passing under the West London Extension Railway, and the Kensington Canal, near to Cremorne Gardens, where a temporary pumping station has been erected, and the sewage is, and will continue to be, lifted into the river, until the Low Level Sewer is completed.

The Chiswick Line commences at Chiswick Mall, and passing near to the river and along the Fulham Road, and Walham Green, again skirts the river to Cremorne Gardens, and will be extended eventually to the permanent pumping station near the Grosvenor Canal.

The Fulham branch commences at Fulham Bridge, and joins the Chiswick line at the King's Road.

The size of the main line varies from 4 feet by 2 feet 8 inches to 4 feet 6 inches in diameter, with a fall of 4 feet per mile, the depth below the surface being from 14 feet to 30 feet. The branch varies in size from 3 feet 9 inches by 2 feet 6 inches to 4 feet 6 inches by 3 feet, its fall being $10\frac{1}{3}$ feet per mile, and its depth about 17 feet.

The Acton branch is carried along the Uxbridge Road from the Stamford Brook, at Wormwood Scrubs, to the Counters Creek Sewer at Royal Crescent, Notting Hill, into which it diverts the water from the higher ground, and which forms a storm-outlet into the Thames, near Cremorne Gardens. The Uxbridge Road Sewer varies from 3 feet 9 inches by 2 feet 6 inches to 4 feet by 2 feet 8 inches; it has a fall of 4 feet per mile, and is about 14 feet deep.

The Chiswick Sewer is $3\frac{1}{4}$ miles long, the Fulham Sewer 1 mile 720 feet, and the Acton branch $1\frac{1}{2}$ mile. Besides these, there are various other minor branches and works. These for the present discharge into a large well or sump, at the temporary pumping station, near Cremorne Gardens.

The works were executed mainly through gravel, charged with such large volumes of water, that it was necessary to lay stoneware pipes under the inverts of the sewers, to lower the water in the ground, and to convey it to numerous and powerful steam pumps in the line of the works, before the sewers could be constructed. The operation of passing under railways and canals, difficult in so treacherous a subsoil, was successfully accomplished, and no serious accidents or failures occurred.

The Northern Outfall Sewer is a work of peculiar construction; as, unlike ordinary sewers, it is raised above the level of the surrounding neighbourhood in an embankment, which has the appearance of a railway embankment, and it is carried by aqueducts over rivers, railways, streets, and roads. Rails upon which the contractors' steam-engines and trucks have been constantly travelling, are at the present time laid along the top of it. It commences by a junction with the High and Middle Level Sewers, at the Penstock Chamber at Bow, and passes immediately under the rails of the North London Railway, which are carried over it on girders. It then passes under Wick Lane, which has been raised 18 feet, and then over the River Lea by a wrought-iron aqueduct of 57 feet span. This aqueduct consists of two wrought-iron culverts of the same section as the brick sewers, and over these is formed a roadway with parapet walls, the whole being supported by three wrought-iron plate girders. Indeed, all the aqueducts on this line of sewer are so constructed as to carry a wide roadway upon plates and girders on the top of them. Four other streams between the River Lea and the Stratford Road are crossed over, by iron tubes, of spans varying from 18 feet to 45 feet; and the sewers pass close under the rails of the Great Eastern Railway, where it is on an embankment, the work having been executed without any interference with the traffic on the railway. The Outfall Sewer, up to this point, consists of two culverts, each 9 feet by 9 feet, placed side by side, formed with upright sides, semicircular crowns and segmental inverts. These are built upon a solid concrete embankment, carried through the peat soil down to the gravel, which is in many places at a great depth below the surface. Concrete is also carried up with a slope of 1 to 1, so as to form an abutment to the sides of the sewers. The whole structure is then covered with an earthen embankment, with slopes of 1½ to 1, the foot of which is fenced in by a quick-set hedge and a ditch, and presents the appearance of a simple railway embankment. It is executed of sufficient strength to carry a railway or a roadway on the top, and will no doubt, at a future time, be used for some such public purpose. The outer earthen embankment not being carried below the surface, has from time to time subsided into the peat marshes through which it is formed, and these settlements have been made good in the ordinary manner; but the sewer and its concrete embankment have shown no sign of settlement or fracture since their completion. At the Stratford Road, the top of the sewer was depressed and carried under the road by four culverts, each 6 feet high and 7 feet 3 inches wide, covered with cast-iron plates. A large amount of property was purchased, and the road raised 10 feet upon a viaduct to pass over the sewer at an inclination of 1 in 50. From the Stratford Road the double line of sewer is continued over Abbey Mill Lane, by two selfsupporting wrought-iron tubes, to the Abbey Mills pumping station, where the contents of the Low Level Sewer will be raised 36 feet. From this point three parallel lines of sewer, of the same form and dimensions as those before described, are continued to the outlet at Barking Creek. Gates and overflow weirs are formed in the line of these culverts, enabling the sewage to be turned into either or all of them at will, and preventing any one of them being at any time overcharged. Just beyond the pumping station, the three lines pass over the Channelsea River and Abbey Creek, by cast-iron culverts, supported by four wrought-iron plate girders of two spans of 40 feet each. They are then carried over Marsh Lane, the North Woolwich and the Bow and Barking Railways, by aqueducts somewhat similar to those already described. These railways were lowered to enable the sewer to pass over them; for the sewer being reduced to a minimum uniform fall of 2 feet per mile, could not be raised or depressed like a railway, to accommodate its levels to those of previously existing works. This, indeed, constituted one of the great difficulties experienced in laying out the line of the Outfall Sewer, for the district through which is passes was already closely intersected by public works. For the same cause, also, the thickness of the ironwork, between the bottom of the sewer and the under side of the aqueduct, was reduced to a minimum, and it does not in most cases exceed 5 inches.

For a distance of about 1½ mile at the lower end of this sewer, so great was the depth of the peat in the marshes, that it would have been very costly to have excavated the whole of the ground down to the gravel, and to have filled it in with solid concrete. The plan therefore adopted for the foundations of this length, was to excavate cross trenches 6 feet 6 inches wide, at distances of 21 feet from each other, down to the solid ground, and to fill these in with concrete piers, upon which brick arches of four rings in thickness were turned, and the sewers were built upon these arches. The top of the bank is 40 feet wide, and in some cases 25 feet above the level of the marshes.

From the crossing of the Bow and Barking Railway, the triple sewer is constructed in brickwork to its outlet at Barking Creek; crossing in its route the five following roads, viz.—Balaam Street, Plaistow, Barking Road, Prince Regent Lane, Blind Lane, and East Ham Hall Manor Way, which were raised for the purpose 6 feet, 8 feet, 13 feet, 20 feet, and 16 feet, respectively.

The invert of the sewer at the outlet is about 18 inches below high-water mark; but before entering the river, the sewage falls over an apron a depth of 16 feet, and is discharged by nine culverts, each 6 feet high by 6 feet wide, laid at the level of low-water spring tides. The three upper sewers are, however, fitted with penstocks, before reaching the tumbling bay, to afford the means of closing the river outlet, and of diverting the sewage into the reservoir, in which it will be stored for about eleven hours per tide. The reservoir is so situate, that the sewers form one side of it, and a communication is made between them by sixteen openings, through which, when the penstocks are closed, the sewage enters the reservoir, and is there stored until high water. The sluices at the lower part of the reservoir are then opened, and allow the sewage in the reservoir to be discharged into the river through the nine 6-feet culverts; and the three penstocks, at the river outlet, being opened at the same time, the sewage is simultaneously discharged directly into the river from the outfall sewers without being first passed through the reservoir. The upper openings from the outfall sewer into the reservoir are also fitted with sluices, to enable the communication between the sewer and the reservoir to be shut off in cases of necessity, and the whole of the waters to be discharged over the tumbling bay. At the river end of the nine culverts, a channel is cut in the bed of the river, the floor of which is formed of concrete, and the sides protected by campsheathing, so that the sewage is discharged into the bed of the river at the time of high water. The whole of this line is practically completed, and has been in operation since March, 1864.

The Barking Reservoir is $16\frac{3}{4}$ feet in average depth, and is divided by partition walls into four compartments, covering altogether an effective area of 412,384 superficial feet, or about $9\frac{1}{2}$ acres. The external and partition walls are of brickwork, and the entire area is covered by brick arches, supported upon brick piers, the floor being paved throughout with York stone. The reservoir, being almost entirely above the general surface of the ground, is covered by an embankment of earth, rising about 2 feet above the crown of the arches. The ground over which it is built being unfit to sustain the structure, the foundations of the piers and of the walls were carried down in concrete to a depth of nearly 20 feet.

The sewage is ordinarily prevented rising above a certain level in the reservoirs, by means of a weir or overflow in the partition walls, which are built hollow, the spaces communicating with the discharging culverts below the outfall sewers. In cases of necessity, however, the reservoirs can be filled above the weir level, by closing the penstocks fitted to the discharging culverts at their entrance into the tumbling bay before referred to. A culvert, communicating with the river, is built at the back of the reservoir, having openings into each compartment fitted with penstocks, and by these means any one of the compartments may be filled with tidal water at the top of the tide, and be flushed out by its discharge at the period of low water. This reservoir is completed, and has been in efficient operation since August, 1864.

The Abbey Mills Pumping Station will be the largest establishment of the kind on the Main Drainage Works, providing, as it does, engine power to the extent of 1,140 H.P., for the purpose of lifting a maximum quantity of sewage and rainfall of 15,000 cubic feet per minute a height of 36 feet.

The engine power is here divided amongst eight engines, each being equivalent to 142 H.P. Each engine is furnished with two boilers, making sixteen boilers in all. The engines are contained in one building, cruciform in plan, and are arranged in pairs, two engines in each arm of the cross. These engines, as in all the other pumping establishments on these works, are expansive, condensing, rotative beam engines, but are somewhat more powerful than those used elsewhere, the cylinders being 4 feet 6 inches in diameter with a length of stroke of 9 feet. The pumps differ also in being double acting, a circumstance which allows of the air-pump, &c., being worked from the main beam, instead of from a distinct beam, as at the other stations. Each engine works two pumps, having a diameter of 3 feet 10½ inches and a length of stroke of 4½ feet. The boilers are each 8 feet in diameter, and 30 feet long, with double furnaces.

The engine-house is divided in height into three compartments, the lower one being the pump-well, into which the sewage is conveyed from the Low Level Sewer, the intermediate one forming a reservoir for condensing water, and the upper being more correctly the engine-house, in which are contained the eight engines. The lower part of this building will be laid about 3 feet above the bottom of a thick stratum of clay, overlying a considerable thickness of sand with water, through which the foundations are to be carried, by piling, on to a bed of firm gravel below. The boiler-houses and other portions of the work will be founded upon the clay stratum overlying the sand. As these deep foundations are situate in close proximity to the Northern Outfall Sewer, which is contained in an embankment above the general level of the ground, great caution will be requisite to prevent any settlement in that sewer. The boiler-house and coal stores are to be built between the outfall sewer and the engine-house, keeping the deep excavations as far distant from the sewer as practicable. The coal stores will be built with their floors level with the stoke-holes in the boiler-house, and tramways will be laid from one to the other; one side of the coal stores forming also the front side of the boiler-house. This floor will be only slightly below the present surface of the ground, which is 6 feet below high water. Tramways will be laid from the top of the coal stores to the Abbey Mill River, adjacent to the works, where a wharf wall will be built for landing coals and other materials.

The sewage from the Low Level Sewer, before entering the pump-wells, will pass through open iron cages, the bars of which will intercept any substances likely to interfere with the proper action of the pump-valves; and the cages, when requisite, will be lifted above ground, by proper gearing, and the intercepted matter be discharged into trucks, or otherwise removed. The sewage will then pass into the wells, and be lifted by the pumps, through hanging valves, into a circular culvert of cast iron, and thence will be forced into any of the three culverts forming the Northern Outfall Sewers.

It is fortunate that these works were not projected in the year 1306, when coal was first introduced into London, and was regarded as such a nuisance, that the resident nobility obtained a royal proclamation to prohibit its use under severe penalties, for this pumping station alone will consume about 9,700 tons of coal per annum.

The cost of pumping is not, however, entirely in excess of the former expenditure upon the drainage; for the cost of removing deposit from the tide-locked and stagnant sewers in London formerly amounted to a sum of about £30,000 per annum; and the substitution of a constant flow through the sewers, by means of pumping, must necessarily largely reduce the deposit, and consequently the annual cost of cleaning.

The South Side of the Thames.

The High Level Sewer and its Southern Branch, correspond with the High and the Middle Level Sewers on the North side of the Thames. The Main Line commences at Clapham, and the Branch Line at Dulwich, and they together drain an area of about 20 square miles, including Tooting, Streatham, Clapham, Brixton, Dulwich, Camberwell, Peckham, Norwood, Sydenham, and part of Greenwich. Both lines are constructed of sufficient capacity to carry off all the flood-waters, so that they may be entirely intercepted from the low and thickly-inhabited district, which is tide-locked and subjected to floods. The storm-waters will be discharged into Deptford Creek, whilst the sewage and a limited quantity of rain will flow by four iron pipes, each 3 feet 6 inches in diameter, laid under its bed into the Outfall Sewer.

The two lines unite in the New Cross Road, near to the New Cross Station on the Brighton Railway, and they are constructed side by side along that road to Deptford; but at the New Cross Station, the Branch Line is 10 feet above the Main Line, but by falling at a more rapid inclination, it arrives at the same level as the Main Line at Deptford Broadway. The Branch is 4½ miles in length, of which 1,000 feet were executed in tunnel, at depths varying from 30 feet to 50 feet. Its size varies from 7 feet in diameter to a form 10 feet 6 inches by 10 feet 6 inches, with a circular crown and segmental sides and invert, and its fall varies from 30 feet per mile at the upper end, to 2⅓rd feet per mile at the lower end. The soil through which it passes is mostly a mixture of sand and clay, containing cockle and other shells to a large extent. The old Effra Sewer, which fell into the river near Vauxhall Bridge, has been diverted through this sewer to a new outlet at Deptford, and the old line has been filled in and abandoned. Two subsidiary branches have been extended from this sewer at Dulwich—the one to Crown Hill, Norwood, and the other to the Crystal Palace.

The Main Line varies in size from 4 feet 6 inches by 3 feet at the upper end, to 10 feet 6 inches by 10 feet 6 inches, of the same form as the branch by the side of which it is constructed. The double line of sewer occupies the whole width of Church Street, Deptford, and the inverts being below the foundations of the houses on each side of the street, the walls of the houses were underpinned, and the spaces between them and the sewers filled in with concrete. The subsoil here consisted of loamy sand and gravel with large quantities of water, and, to add to the difficulty of the work, the old Ravensbourne Sewer, which passed through the centre of the street, had to be taken up, and its waters diverted during the progress of these operations.

The outlets of the two sewers, 10 feet 6 inches by 10 feet 6 inches, are each fitted with two hinged flaps, one above the other, the lower one being usually fixed close, so as to form a dam to drive the water through the iron pipes into the Outfall Sewer, but the upper one hanging free, in order to serve as a tide flap, and allow of the exit of the sewage into the Creek, when it rises in the sewer to a sufficient altitude. In cases of heavy floods, however, the lower flap can be opened, to admit of a free and full discharge from the sewers into the Creek. The entrances to the iron pipes are in troughs, or sumps, in the large sewers, a short distance within or behind the outlet flaps, and are fitted with penstocks, to shut off the sewage from the Outfall Sewer in case of need.

The falls of the Main Line are, at the upper end 53 feet, 26 feet, and 9 feet per mile to the Effra Sewer at the Brixton Road, and thence to the outlet 2⅓rd feet per mile. The sewer is executed in brickwork, varying in thickness from 9 inches to 22½ inches, one-half, that forming the invert, being in Portland cement, and the remainder in blue lias mortar.

The whole of this line is completed, and has been in successful operation since January, 1863.

The Low Lewel Sewer does not follow the course of the River, as on the North side, but, commencing at Putney, it takes a more direct line, through low ground once forming the bed of a second channel of the Thames, and drains Putney, Battersea, Nine Elms, Lambeth Newington, Southwark, Bermondsey, Rotherhithe, and Deptford, comprising an area of 20 square miles. The surface of this area is mostly below the level of high water, and is, in many places, 5 feet or 6 feet below it, having at one time been completely covered by the Thames. The sewers throughout the district have but little fall, and, except at the period of low water, were tide-locked and stagnant; consequently, after long-continued rain, they became overcharged, and were unable to empty themselves during the short period of low water. The waters, therefore, were constantly accumulating, and many days frequently elapsed, after the cessation of the rain, before the sewers could be entirely relieved, the sewage in the interim being forced into the basements and cellars of the houses, to the destruction of much valuable property. The want of flow also caused large accumulations of deposit in the sewers, the removal of which was difficult and costly. These defects, added to the malaria arising from the stagnant sewage, contributed to render the district unhealthy; and it was with reference to the condition of this district, that the late Mr. R. Stephenson and Sir W. Cubitt so forcibly described the effect of artificial draining by pumping, as equivalent to raising the surface a height of 20 feet.

The Low Level Sewer has, in fact, rendered this district as dry and as healthy as any portion of the Metropolis. Its length is about 10 miles. Its size varies from a single sewer 4 feet in diameter at the upper end, to two culverts, each 7 feet high by 7 feet wide, at the lower end, and its fall ranges from 4 feet to 2 feet per mile. The lift at the outlet of the sewer is 18 feet. This sewer was constructed through a stratum of sand and gravel overlying the clay, such as is frequently found in the beds of rivers, and copiously charged with water. Some very successful instances of tunnelling under canals, railways, and house property, occurred in the construction of this work; and a mode of pumping in a quick-sand, and rendering it dry and firm without drawing off the sand, was adopted, which will be more particularly described in another part of this Paper. Much difficulty was experienced in executing a portion of this work close to and below the foundations of the arches of the Greenwich Railway, and under Deptford Creek, owing to the large volume of water there met with. This was, however, at last surmounted, by sinking two iron cylinders, each 10 feet in diameter, through the sand, to a depth of about 45 feet, the water being kept down by pumping, at the rate of from 5,000 gallons to 7,000 gallons per minute. The sewer was carried under

Deptford Creek, and the navigation was kept open, by constructing a coffer-dam into the middle of the Creek, and by executing one-half of the work at a time. All these works were completed with but few and unimportant casualties.

The sewers of this district had been constructed, generally, with a fall from west to east, and had been connected with each other in such a manner that, in case of one becoming first overcharged, it might be relieved by its neighbour, and the sewage be reduced to a uniform level all over the district. Taking advantage of this circumstance, an important branch was constructed from the Low Level Sewer at High Street, Deptford, towards the river to St. James's Church, Bermondsey. This branch, by intersecting the Earl, the Duffield, and the Battle Bridge Main Sewers, relieves a large and populous district. Its length is about 2 miles, its size varies from 5 feet to 5 feet 6 inches in diameter, and its fall is 4½ feet per mile. Its depth varies from 15 feet to 40 feet below the surface, and it has been in successful operation since January, 1864.

The Deptford Pumping Station is situated by the side of Deptford Creek, and close to the Greenwich Railway Station. The sewage is here lifted from the Low Level Sewer, a height of 18 feet, into the Outfall Sewer. An iron wharf wall and barge-bed, 500 feet long, has been constructed at the side of the creek, and is provided with a crane and tramways, for landing coal or other materials. Four expansive, condensing, rotative beam engines, each of 125 H.P., and capable together of lifting 10,000 cubic feet of sewage per minute a height of 18 feet, are here constructed. These engines are worked by ten Cornish single-flued boilers, each 30 feet long and 6 feet in diameter. The cylinders are 48 inches in diameter, with a length of stroke of 9 feet, and the pumps, two of which are worked by one engine direct from the beam, are single-acting plunger pumps, the diameter of the plungers being 7 feet and the length of the stroke 4½ feet. One pump is placed on the beam, midway between the steam cylinder and the centre pillars, and the other midway between the centre pillars and the fly-wheel. The air, the feed, and the cold water pumps are actuated by a separate beam, attached to the cylinder end of the main beam. The pump valves are leather-faced hanging valves, and the sewage is discharged through them into a wrought-iron culvert placed on the level of the Outfall Sewer, and connected with it by a brick culvert, which receives also the sewage from the High Level Sewer, previously brought by gravitation under the creek, through four cast-iron pipes 3 feet 6 inches in diameter. Both streams enter the Outfall Sewer, and are together conveyed to Crossness, where they are again lifted. The chimney shaft at this station is 7½ feet in diameter at the base and 6 feet at the top;

its height is 150 feet, and the furnaces draw from the sewers and the engine-well to assist in the ventilation of the works. The accommodation for coals is ample, the sheds covering an area of 18,000 superficial feet.

Provision is made, by gratings, for the interception of the larger substances brought down by the sewers, in the same manner as at Crossness.

This Station is completed, and the engines have been in operation since May, 1864.

The Southern Outfall Sewer conveys the sewage which flows into it from the High Level Sewer by gravitation through the four iron culverts laid under Deptford Creek, and that which is pumped into it from the Low Level Sewer, from Deptford through Greenwich and Woolwich to Crossness Point in the Erith Marshes. It is not, like the Outfall Sewer on the North side, constructed above the level of the ground, but is entirely under ground for its whole length of $7\frac{3}{4}$ miles. It is 11 feet 6 inches in diameter, formed in brickwork generally 18 inches thick, and has a fall of 2 feet per mile. The bottom of the sewer is 9 feet below the level of low water at its outlet into the river, so that it can discharge into the river at and near to low water, by gravitation, in case of necessity; but ordinarily the mode of discharge will be by pumping into the Crossness Reservoir. It has been constructed at a depth of about 16 feet below the surface, except through Woolwich, where the depth ranges from 45 feet to 75 feet. The soil through which it passes it mostly gravel and sand, but the Woolwich tunnel, which is the principal feature of the work, is partly in the chalk. One mile of this tunnel was executed under the town of Woolwich, without any casualties or settlements.

The large volume of water met with in the Marshes, rendered the construction of that portion of the work very costly. These marshes originally formed part of the Thames, and were first enclosed in the reign of Edward I., by the monks of Lesnes Abbey; 2,000 acres were afterwards flooded, by the bursting of the river banks, in the reign of Henry VIII., and were not again reclaimed until the reign of James I. They would have suffered a similar fate, in the year 1864, in consequence of the breach caused in the river bank by the explosion at Messrs. Hall's Powder Magazine, had not a large number of workmen then engaged upon the Main Drainage works at Crossness, at once, by prompt and energetic efforts, afterwards efficiently aided by the military, repaired the breach before the rising of the following tide.

This sewer was completed in June, 1862, and has been in successful operation since that period.

The outfall of the sewage on the South side of the Thames is at the Crossness Reservoir and Pumping Station. The sewage is discharged into the river at the time of high water only, but the sewer is at such a level, that it can discharge its full volume by gravitation about the time of low water. Its outlet is ordinarily closed by a penstock placed across its mouth, and its contents are raised by pumping into the reservoir, which is built at the same level as that on the North side; and, like it, it stores the sewage, except for the two hours of discharge after high water. The sewage is thus diverted from its direct course to the river, into a side channel leading to the pump well, which forms part of the foundation for the engine-house; from this well it is lifted by four beam engines, each of 125 H.P., and actuating, direct from the beam, two compound pumps, each having four plungers. The engines are condensing, rotative beam engines, the cylinders being 4 feet in diameter, with a length of stroke of 9 feet; they are situate at the end of the main beam, which is 40 feet in length, the fly-wheel connecting rod being attached to the further extremity, and the pump rods situate on either side of the beam centre. The air, the feed and the cold-water pumps are actuated by a separate or counter beam, fixed at one end to a rocking lever, and attached at the other to the main beam. The cylinders are supplied from twelve Cornish boilers, each 6 feet in diameter and 30 feet long, having an internal furnace and flue 3 feet in diameter, and being set so as to have the second heat carried with a split draught along the sides, and the third heat under the bottom of the boiler into the main flue leading to the chimney.

The maximum quantity of sewage to be lifted by these engines will ordinarily be about 10,000 cubic feet per minute; but during the night, that quantity will be considerably reduced, while on the other hand it will be nearly doubled on occasions of heavy rainfall. The lift also will vary from 10 feet to 30 feet, according to the level of water in the sewer and in the reservoir into which it is lifted. These variable conditions of working led to some difficulty in the arrangement of the engines and pumps, which it has been endeavoured to meet by the arrangement of pump plungers before alluded to. The pumps, which are single-acting, are placed equidistantly on each side of the beam centre, the pump cases being each 12 feet in diameter, fitted with four plungers 4 feet 6 inches in diameter. These plungers are placed in pairs, each pair being worked from a cross-head on the main beam, which is in two flitches with this object, and arrangements are made for throwing either pair of plungers out of gear. By this means the capacity of the pumps may be varied, in the proportion of 1, 2, or 3, as the inner pair, outer pair, or both pairs are thrown into gear. The sewage is discharged into a wrought-iron trough, through hanging leather-faced valves, which are suspended from wrought-iron shackles, and fitted with the wrought-iron back and front plates. Each valve is 12 inches by 18 inches. It should be mentioned, that substances which might prevent the proper action of the valves are intercepted before reaching the pumps, by a wrought-iron grating placed in front of the openings to the pump-well, the substances so intercepted being lifted from the face of the grating by an endless chain, with buckets or scrapers and combs attached, working vertically in front of and in close contact with the grating, the teeth of the comb passing between the bars. On the descent of the chain, the buckets are overturned and discharge their contents into a trough, from which they will be removed by manual labour.

The sewage, after being delivered from the pumps into the wrought-iron trough, is discharged through brick culverts into the reservoir, or, in case of need, provision is made for its discharge through other culverts directly into the river. After being stored in the reservoir until the time of high water, the sewage is discharged by a lower set of culverts into the river. There are two tiers of eight openings in each compartment of the reservoir, the upper eight for the admission of the sewage from the pumps to the reservoir, and the lower eight for its discharge into the river, the apertures in all cases being opened and closed by penstocks.

The reservoir, which is 6½ acres in extent, is covered by brick arches supported on brick piers, and is furnished with weirs for overflows, and with a flushing culvert. Its height, level, and general construction are similar to that at Barking Creek, already described. Over the reservoir are built twenty-one cottages, for the engineers and other persons employed upon the works.

The ground upon which the whole of these works were constructed consists of peat, sand, or soft silty clay, and affords no sufficient foundation within 25 feet of the surface. To obviate this difficulty, and to reduce the expense of the foundations as much as possible, the culverts on the various levels were built, as far as practicable, in the same trenches, one above the other; the lowest, leading from the Outfall Sewer to the pump-wells, support those discharging the sewage from the reservoir, which latter in turn support those leading from the pumps into the reservoir. The requirements of the pump-wells necessitated that the walls of the engine-house should be carried down to the level of the gravel, independently of the nature of the ground; but such was not the case with the boiler-house. The boilers and stoke-hole floor are supported on arches, which spring from walls brought up from the gravel, and the space below the boiler-house floor is made available as a reservoir for condensing water. The water from the hot and cold wells of the engines is conveyed hither, and one compartment is set apart as a chamber for cooling the water from the hot well, previous to its being used again for condensing water. With the same object, of saving separate foundations, coal stores and workshops have been erected, partly on the external walls of the reservoir, and partly on the culverts in front of them, large coal stores being also provided in front of the boiler-house, and on a level with the stoke-holes, into which the coals will be brought on tramways. A tramway is also provided for the upper level coal-sheds, on the level of the tops of the boilers, whence the coals will be shot into the stoke-holes below. Tramways are also laid from the coal-sheds to the river, and jetties are carried out into the river, to facilitate the landing of coals, and their transfer to the stores. A wharf wall has been constructed along the river frontage of the works, for a distance of about 1,200 feet, by which a large portion of the 'saltings' has been reclaimed. The wall is of brick, carried upon brick arches, which rest upon piers formed of iron caissons filled with concrete, and which are carried down to the gravel.

The chimney into which the flues from the boilers are conveyed is square on plan externally, being 8 feet 3 inches internal diameter throughout, and 200 feet in height; it is founded upon a wide bed of concrete, brought up from the gravel, which is here 26 feet below the surface.

The reservoir, as well as the several culverts and the pump-wells, are all connected by flues with the furnaces of the boilers, for the purposes of ventilation, in a manner similar to that adopted at the Deptford and other pumping stations.

The outlet into the river from the Outfall Sewer, which was constructed in connection with these works, consists of twelve iron pipes, each 4 feet 4 inches in diameter, carried under the 'saltings' into a paved channel formed into the bed of the river. These pipes are gathered into the single sewer, by culverts in brickwork on the land side of the wharf wall, the culverts being gradually reduced in number, and their dimensions increased, as they approach the junction with the large Outfall Sewer. The whole of these works have recently been completed.

The tunnels successfully completed under circumstances of difficulty, and where failure would have been very disastrous, were numerous.

The tunnelling, and the formation of the sewers through quicksands charged with large volumes of water, existing under various portions of the metropolis, but more particularly in the low-lying districts on the south side of the Thames, where rendered practicable and safe, by a mode of pumping the water out of the ground, without withdrawing the sand, which was adopted and perfected during the progress of these works.

During the Author's early connection with the Metropolitan Sewers, several disastrous results of pumping in quicksands had occurred, in consequence of the withdrawal of the sand from under the foundations of the adjoining houses. This caused unequal settlements and fissures in the walls, so that the buildings had eventually to be pulled down and rebuilt. The Victoria Street Sewer through Scotland Yard is perhaps one of the most serious instances of this kind; portions of the War Office, Fife House, the United Service Museum, the Office of Works and other valuable property were then more or less injured. One of the first works executed by the Author, upon his appointment, was the reconstruction of this sewer, from which a branch sewer was subsequently constructed, through the same soil, close underneath the Clock Tower of the Horse Guards, without the slightest damage to that important and heavy building.

The sewers in Tothill Street, Duke Street, and other streets in the neighbourhood of Great George Street, Westminster, being in peat and sandy soils charged with water, were not formed without considerable risk. The late Mr. Brunel was at one time under serious apprehension lest his residence should subside into the peat on which it stands, the sewer trench having been opened to a great depth close to it; and he afterwards expressed much satisfaction at the precautions adopted to obviate such a catastrophe.

The cases are too numerous to be here mentioned, but a few of the more prominent may be alluded to. The line of tunnel from Kennington Church to the Old Kent Road, a distance of about 1,000 feet, is close under the basements of a large number of houses, the top of the tunnel being only from 10 feet to 12 feet below the surface, and the diameter being about 10 feet. The water was pumped out of the sand, for this length of tunnel, at the rate of about 8,000 gallons per minute. The same sewer was carried, through similar soil, under the Grand Surrey Canal, and within 8 feet of the water in it; and again under the same canal in the Deptford Lower Road, where the distance between the top of the tunnel and the water in the canal was only 6 feet 4 inches, the whole of the soil being gravel and sand, with 1 foot of puddle in the bottom of the canal.

The Regent's Canal in the Caledonian Road was also tunnelled under, the distance between the top of the tunnel and the water in the canal being only 2 feet, so that the miners could hear the barges as they passed over their heads scrape against the ground; this was, however, executed in clay. Another tunnel has been formed 33 feet under the rails of the West London Railway, and under the Kensington Canal. Sewers were constructed under the London and Brighton, the North Kent, and several other railways, without any interruption to the continuous traffic on them.

The method adopted for pumping out the water, without drawing off the sand, and for building the brickwork in ground so charged with water, was first to sink, in some convenient position, near the intended works, a brick well to a depth of 5 feet or 6 feet below the lowest part of the excavation. In some cases, where the depth was great, an iron cylinder was sunk below the brickwork, and the bottom and sides of the well were lined with shingle, which filtered the water passing into it, and exposed a large surface of this filtering medium. Earthenware pipes were carried from this well and laid below the invert of the intended sewer, small pits being formed at the mouths of these pipes, to protect them from the deposit. By these means, the water has been successfully withdrawn from the worst quicksands, and they have been rendered firm and dry for building on. Iron plates have, in olden times, been laid underneath the brickwork of the invert of the sewers, to support them in such treacherous ground, but concrete forms both a cheaper and a better foundation, and unless the ground is so dry and solid that it can be excavated to the exact form of the sewer to be placed on it, there is no portion of the work more important, than the effectual backing of the invert and the haunches with concrete.

The bricks used in the works have been mostly picked stocks and Gault clay bricks, and the inverts were occasionally faced with Staffordshire blue bricks. The brickwork is laid in blue lias lime mortar, mixed in the proportions of 2 of sand to 1 of lime for one-half or two-thirds of the upper circumference of the sewers, and the remainder has been laid in Portland cement, mixed with an equal proportion of sand. A very considerable length of sewer has been laid entirely in cement. A double test of the quality of the cement has been used, which has been found most effective, and has tended greatly to improve the manufacture of that material, so important in building operations. The specifications provide, that the whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the bushel, and capable of maintaining a breaking weight of 500 lbs., on 1½ square inch, seven days after being made in an iron mould, and immersed in water during the interval of seven days.

The total cost of the Main Drainage Works, when completed, will have been about £4,100,000. The works have been executed under the immediate superintendence of the Assistant Engineers, Messrs. Lovick, Grant, and Cooper. The principal contractors have been Messrs. Brassey, Ogilvie, and Harrison; Mr. Webster; Mr. Furness; Messrs. Aird and Sons; Mr. Moxon; Messrs. James Watt and Co.; Messrs. Slaughter; and Messrs. Rothwell and Co. The sum for defraying the cost of these works is raised by loan, and paid off by a *3d* rate levied on the metropolis, which produces £180,262 per annum, the rateable value being £14,421,011, and the principal and interest of the loan will be paid off in forty years.

There are about 1,300 miles of sewers in London, and 82 miles of main intercepting sewers. Three hundred and eighteen millions of bricks, and 880,000 cubic yards of concrete have been consumed, and 3½ million cubic yards of earth have been excavated in the execution of the Main Drainage Works. The total pumping power employed is 2,380 nominal H.P.; and if at full work night and day, 44,000 tons of coals per annum would be consumed, but the average consumption is estimated at 20,000 tons.

The sewage on the North side of the Thames at present amounts to 10 million cubic feet per day, and on the South side to 4 million cubic feet per day; but provision is made for an anticipated increase up to 11½ million on the North side, and 5¾ million on the South side, in addition to 28½ million cubic feet of rainfall per diem on the North side, and 17¼ million cubic feet per diem on the South side, or a total of 63 million cubic feet per diem, which is equal to a lake of 482 acres, 3 feet deep, or fifteen times as large as the Serpentine in Hyde Park.

The whole of the Main Drainage scheme is now completed, with the exception of the Low Level Sewer on the North side of the Thames, which is being formed in conjunction with the Thames Embankment and the new street to the Mansion House, and will therefore probably not come into operation for two years. The proportion of the area drained by that sewer is one-seventh of the whole. Some sections of these works have been completed, and have been in working operation, from two to four years, and the largest portion of the work has been completed and has been in operation for more than a year, so that the principles upon which the scheme has been based have already been fairly tested.

The communication is accompanied by numerous Appendices, including Tables of Rainfall, particulars of many instances of tunnelling, as well as a list of the fossil remains, antiquities, &c., found in excavating for the works.[1] It is illustrated by a Map of London, and by models and enlarged diagrams of some of the principal works, as well as by a complete set of the specifications and of the contract drawings, which is presented to the Institution by the Author.

[1] A very large number of ancient animal remains, curiosities, and coins were found in different portions of the work; many of these were sold by the workmen, and were not given up to the Board. Most of them may be seen at the British Museum. They consist chiefly of the bones of elephants, whales, and the horns of deer and oxen, with some flint implements of war and ancient human skulls, stone and leaden coffins, and a number of Roman coins of various reigns.

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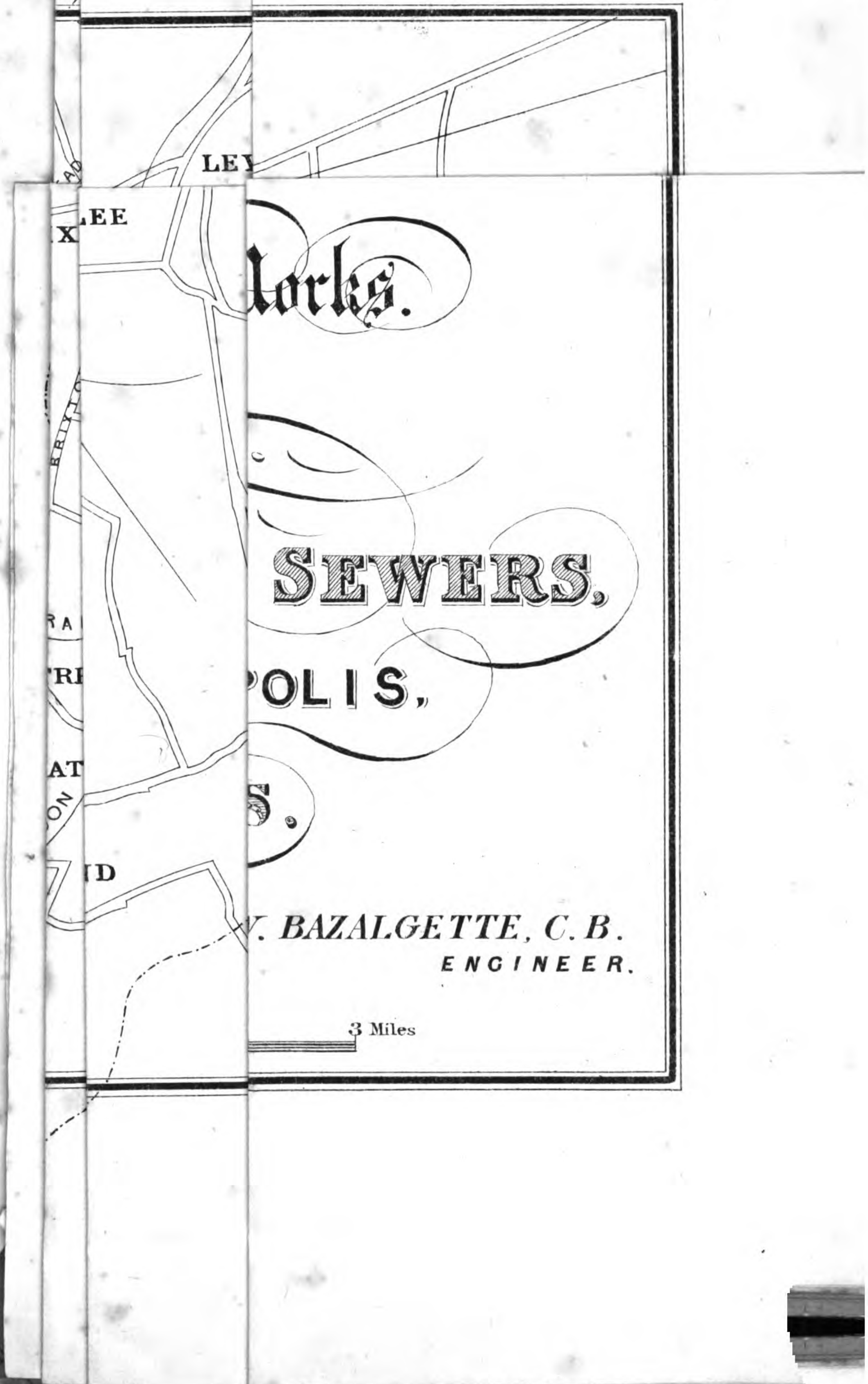
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