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CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

No. 1,304.—"The Treatment of Town Sewage."[1] By ARTHUR JACOB, B.A., Assoc. Inst. C.E.

THE disposal of town sewage is one of the most important problems that has presented itself for solution in the whole course of sanitary research, and whilst the methods adopted for the removal of liquid refuse from human abodes have been successfully determined by practice, a very great divergence of opinion exists even now with regard to the mode of dealing with that refuse at the outfall.

Waste, on the most gigantic scale, has been permitted for ages, and is still allowed to continue, even at the very centres of civilization, and rivers continue to be polluted because the public cannot feel assured as to the safest and most economical treatment of their sewage.

In summarizing the various processes that have been suggested for the treatment of sewage, each will come under one of the following general heads:—

1st. Chemical.
2nd. Mechanical.
3rd. Agricultural.

It is proposed to review, briefly, the attempts made up to the present time to deal with sewage by each of the first two classes and then to enter more fully into the process of sewage irrigation, which so far appears to offer the most efficient solution of the question.

Before treating however of the Disposal of Sewage, it may be well to consider briefly the merits of what is called the midden system, not as having any close connection with the question of the treatment of sewage, but because endeavours have been, and are still being made, to offer the dry system to the public as a panacea for all the trouble and danger in which they find themselves

[1] The discussion upon this Paper occupied portions of two evenings.

involved. The object of this system is to treat human excrement by dry earth, ashes, or some other absorbent material, so as to deodorize it, and deprive it of its offensive properties. No doubt dry and absorbent materials generally, and certain kinds of earth in particular, possess the property of destroying smell, and of arresting, to a great extent, the decomposition of animal refuse. This is probably only an illustration of the theory propounded by the celebrated chemist, M. Dumas, that chemical action does not take place at ordinary temperatures without the presence of water. But the admission, that excreta may be successfully treated by the dry process, will never lead to the conclusion, that this system will obviate the necessity for drainage.

An ordinary household of, say, six persons, enjoying a proper water-supply, will consume for all purposes about 20 gallons per head per diem, or a total daily quantity of 120 gallons, which must necessarily be fouled in its use, and pass away from the house laden with dangerous impurities. If earth closets are used instead of water-closets, a certain quantity of water, perhaps as much as 4 or 5 gallons per head, may be saved, but there will still be 15 gallons of water fouled with grease, soapsuds, vegetable refuse, and other materials of a highly putrescible kind, which must necessarily pass away and be disposed of at the outfall. Under special circumstances, and in certain situations, the earth system is doubtless found applicable; but it is a fallacy to offer it as a substitute for sewerage, and therefore, as it does not remove the difficulty or reduce the amount of sewage to be dealt with in any appreciable degree, the consideration of it may be for the present dismissed.

Chemical Treatment.

Under this heading it is proposed to consider only those methods which aim at the reduction of the evil by some specific chemical treatment, that will either decompose, or render more stable, the offensive constituents of the sewage. Many processes have been devised with one or other of these objects in view; but all have failed to accomplish the desired end. In nearly every case the several modes of treating sewage have had for their object the manufacture of a solid manure, rather than the purification of the effluent water. Nor is it to be wondered at that constantly renewed attempts should be made to extract, from what is worse than refuse, some portion of the immense money value that sewage is so well known to contain.

In reviewing the several processes that have been brought before the public, it is easily apparent that the greater number rely upon the precipitation and collection of the solid or suspended matter from the sewage; as though the impression existed, that this solid matter constituted the major part of the manurial value available. Some even of the most recent attempts appear to be based on this assumption; and although the desired result has been attained in collecting, into a portable form, the solid constituents of the sewage, and in rendering the effluent water transparent and inoffensive, it has been found that the nitrogen, the chief manurial component of the sewage, has, so far as the solution was concerned, not been in any degree appropriated in the process. In short, not more than $\frac{2}{15}$ths of the total money value have been secured, and it does not appear that in any case this amount has been found to produce a commercial return sufficient to defray the cost of manufacture, and to pay a fair interest on the capital outlay for the construction of works.

It is not proposed to consider the details of the several modes of dealing with sewage in order to extract its manurial constituents; a few of the principal inventions that have been tried will be previously reviewed, so as to ascertain what measure of success each has gained.

The Lime Process was tried many years ago. It has been adopted at Blackburn, Leicester, and Tottenham, and is reported on by the Rivers Pollution Commissioners[1] as being in all those places a failure, whether as regards the manufacture of a valuable manure, or the purification of the offensive liquid. The process consists in mixing a certain quantity of milk of lime with sewage as it arrives at the works; then by subjecting the mixture to violent agitation by means of machinery, and allowing it afterwards to pass into large subsidence tanks. In these reservoirs, the mud, composed of the suspended matter and lime, is deposited, and the supernatant water flows away into the nearest watercourse. The mud is afterwards raised from the reservoirs and deposited in pits, where it dries and is afterwards sold for what it will produce. The effect of the process, when properly conducted, is to clarify the sewage to a considerable extent. About 90 per cent. of the organic pollution is removed by the operation, but as regards the soluble impurities the effect is not so satisfactory; the amount of solid material in solution not being

[1] *Vide* "Report of the Commissioners on the Mersey and Ribble Basins," p. 52. Folio. London, 1870.

reduced in amount, and at times it is even increased by the lime dissolving some of the suspended matter.

The analyses made by order of the Rivers Pollution Commissioners demonstrate that "the material which is of the greatest importance to remove from the dissolved constituents of the sewage, that is the nitrogenous organic matter, which enters rapidly into putrefaction,"[1] remains to a great extent in the sewage after treatment. Table 1 illustrates the average extent to which the lime and other processes have been found to succeed from a number of experiments.

What is known as the A B C process has lately been introduced; and professes to free sewage of its "organic and other impurities." This mode of treatment has been tried at Leamington under somewhat unfavourable circumstances; but at Hastings every facility has been afforded for making a fair trial, which, unfortunately, appears in this instance to have failed. Within the last few weeks the Metropolitan Board of Works have decided to permit the company to erect works at the Southern Outfall, where 500,000 gallons will be acted on daily. The materials used in the operation are alum, blood, clay, magnesia, as carbonate or sulphate, some compound of manganese, burnt clay, chloride of sodium, animal and vegetable charcoal, and magnesian limestone. But of these ten substances, it is stated that as many as six may be omitted.[2] Without any desire to criticise the composition of the mixture employed, or the mode of using it, it must be confessed that the nature of the combination of these ingredients with the soluble constituents of sewage does not at first sight appear evident. These substances, as described by the patentees, are mixed together, and added to the sewage to be purified until a further addition produces no further precipitate. The sewage is then thoroughly mixed with the compound and allowed to flow into the settling tanks, where the sediment is left to subside, and the water to flow away into the sea or river. It is supposed that the sediment when pumped up and mixed with a fresh supply of sewage exercises a further purifying effect. The solid material, which is dried by rotation in wire gauze drums, is then ready for the market. The analysis of the sewage before and after treatment shows that about 92 per cent. of the suspended impurity is removed by the process. Of the matters in solution no change of any value is found to take place; the amount of material is actually increased in proportion to the quantity of soluble mate-

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[1] *Vide* "Report of the Commissioners on the Mersey and Ribble Basins," p. 55.
[2] Specification of Messrs. Sillar and Wigner.

rial added, and as for the putrescible matter, the amelioration effected amounts to a reduction of only 55 per cent.

A modification of the lime process has been adopted at Northampton. In addition to the lime, chloride of iron is employed, in the proportion of 6 gallons to every million gallons of sewage. The lime is first added, and then the chloride of iron, and the mixture is subsequently filtered by ascension through a layer of calcined iron ore 8 inches thick, which separates the flocculent matter from the liquid. The deodorization resulting from this process is for the time being complete; but it is found that, although the effluent water enters the river in a clear and apparently inoffensive condition, the process of putrefaction is not permanently arrested. For some distance down the river the water appears to be unpolluted by sewage, but further on the condition is such as to afford substantial ground for complaint; and an injunction has been granted by the Court of Chancery restraining the Improvement Commissioners from discharging the sewage of the town into the river Nen. As is the case with the carbolates of lime and magnesia so it is with the chlorides of iron: the process of decomposition appears to be arrested for a certain time only, and after the use of such agents sewage becomes almost as offensive and prejudicial to health as without their use.

A phosphate process has been lately introduced by Drs. David Forbes and Astley P. Price. "This process is founded on the fact that certain mineral phosphates easily obtainable, especially those containing alumina, when in a hydrated or freshly-precipitated state, eagerly combine with the organic matter contained in the sewage: it being sufficient merely to agitate them in the most fœtid sewage to deprive it of all its odour and colour, even if tinctorial substances of great intensity be present in the solution at the same time; whilst the phosphate of magnesia combines with the ammonia contained in the sewage and precipitates it also in the state of double phosphate of ammonia and magnesia."[1] The mineral phosphate of alumina proposed to be employed exists in large quantity at the island of Alta Vela and in numerous other small islands lying to the south of St. Domingo. The deposit underlies a layer of guano, and is evidently of organic origin, with the remarkable peculiarity of containing little or no lime. The material is calcined, then treated with crude sulphuric or hydrochloric acid, which reduces it to a solution, and

[1] Paper read before the British Association for the Advancement of Science.

in this condition it is added to the sewage. After the admixture is complete the phosphate is precipitated in the hydrated form, along with the organic matter in the sewage, by the addition of such a proportion of milk of lime as will neutralize the acid that holds the phosphates in solution. The deposit rapidly subsides and the supernatant water is then run off.

Experiments recently tried at Tottenham and at Bromley prove the efficiency of this method so far, but it is not claimed for this process that the effluent water is rendered very pure. The greater portion of the ammonia remains in solution, but much of the smell is removed; and samples that have been kept for months have not shown any tendency to fermentation or putrefaction.

It would be premature to express an opinion as to how far this process is likely to prove useful in practice; but it appears to possess certain advantages:—

1st. That the resulting manure, unlike that from the other artificial processes, is really of value. The analyses of Dr. Voelcker show that the deposit is worth about £7 7*s.* per ton,[1] whilst he estimates the manure produced by the A B C process at 19*s.*[2] per ton; and

2ndly. It is considered, with some justice, that the addition of an excess of the phosphate solution would supply to the sewage that phosphoric acid in which it is deficient, and so increase its manurial value.

In estimating the value of this, or any other, process as a means of purifying sewage, the point to which attention must first be directed is the degree of purification effected in the effluent water. As a commercial speculation the manufacture of solid manure from sewage is an important step gained; but for corporations whose duty it is to see that the sewage of their district is discharged into the rivers in an innocuous condition, the purity of the effluent water will ever be the first condition to be fulfilled. Possibly the process here described may, as an accessory to irrigation, prove valuable; but this experience can alone demonstrate.

The foregoing methods of treating sewage, although classed under the general head of 'Chemical' for the sake of convenience, are really to a great extent mechanical in their action. The mechanical process of clearing beer, wine, and other liquids, by means

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[1] Analysis by Dr. Augustus Voelcker.

[2] Journal of the Royal Agricultural Society. Second Series, vol. vi., p. 415. 8vo. London, 1870.

of a coagulum, is very similar to that of precipitating the solid matter from sewage. Without treatment sewage will continue in a turbid and gelatinous condition, but the addition of certain substances, especially those of an astringent kind, produce a coagulum, which lays hold of the suspended matter in the sewage, and carries it to the bottom of the reservoir by its weight.

When all the more effectual modes of chemical treatment are examined, they are found to fall short in their action of the desired result. The largest amount of organic nitrogen extracted in any case from the soluble constituents of sewage by chemical treatment has been about 66 per cent.,[1] which was accomplished by the lime process. Whilst in the use of Holden's process—a mode of treatment by sulphate of iron, lime and coal-dust, which need not be described in detail—the organic nitrogen in solution was increased by the materials used in the process dissolving some of the suspended matter. The chemical modes of treatment are not found to be perfect in their action, even so far as the removal of the suspended matters. Holden's process alone removes the whole of the insoluble materials, and the four other methods extract an average amount of 86 per cent. only.

Mechanical.

The only purely mechanical mode of treating sewage is that of filtration, either downwards or by ascension. This process has not come into actual use except at Ealing, where neither are the conditions favourable nor the results satisfactory: a certain degree of clarification has been accomplished, but, in effect, the partially purified sewage is productive of nuisance, and its impurity is manifested by the presence of the sewage weed in the stream below the outfall.

The experiments on filtration made in the laboratory of the Rivers Pollution Commissioners are calculated to engage the serious attention of engineers, as being an approximation to the much desired result. It is not a necessary inference that a laboratory experiment, or a series of such experiments, is to be taken as conclusive evidence of the success of any process in actual practice: so much indeed is admitted by the Commissioners in their Report, and the possible causes of failure are anticipated by them. The filtration of water for the supply of towns dates

[1] *Vide* "Report of the Commissioners on the Mersey and Ribble Basins," p. 94.

from great antiquity, but until lately the whole of the purification hoped for in the process was the removal of matters held in suspension. It appears to be generally admitted by waterworks engineers that the process of filtration is partly chemical, partly mechanical; and that the soluble impurities may be for the most part removed or altered by the process of filtration through sand. Professor Wanklyn states that an examination made by him of the waters of the Thames collected at Hampton, whence it is taken for the supply of the metropolis, gave 15 parts of albumenoid ammonia in 100,000,000 parts of water. He examined the same water after its passage through the filtering beds of one of the water companies and found the impurity was reduced by the process to one-third. The experiments made on the purification of sewage show, in a still more remarkable degree, that the operation of filtering is almost as much a chemical process as it is a mechanical one; the different soils used as filtering media producing great disparity of result. The first set of experiments, to quote the words of the Report, "was made with two long glass tubes charged, the one with sharp silicious sand, the other with a mixture of equal parts of sand and coarsely-powdered chalk. The London sewage, from the outfall of the Regent Street and Victoria Street sewers in Scotland Yard, was passed continuously upwards through one of these tubes so as to exclude aeration, and subsequently downwards in successive doses through both, so as to cause the air to follow the sewage down the tube between each two consecutive doses. The effluent water was submitted to analysis once a week."[1] The results of these experiments on upward filtration are by no means satisfactory. Of the impurities held in solution but a small percentage was removed, and their substitution by nitrates and nitrites—which represent the putrescible impurity in a converted form—was inconsiderable. The first essential condition for the filtration of sewage, and probably also for the filtration of drinking water, is that it shall be intermittent, so that the interstices of the filtering material shall have time to become aerated. This is not easily practicable with upward filtration, and clearly accounts for the imperfect results attained by the process. The operation of downward filtration, when carried on through different kinds of soil, produced results that may be regarded as very remarkable. The apparatus used consisted of glass tubes 6 feet long and 10¼ inches in diameter: these were placed upright in earthenware pans and were filled

[1] *Vide* "Report of the Commissioners on the Mersey and Ribble Basins," p. 62.

nearly to the top with the soils that were used in the experiments. A sufficient space was left at the top of each cylinder for the reception of the sewage, of which equal quantities were added night and morning. The average composition of the sewage was ascertained at the commencement of the process, for comparison with the effluent water. The degree of purification appeared to depend to a great extent on the rate at which the sewage was passed through the filtering material. Without going into particulars as to the purification effected in each case, it will be sufficient to state, that in every instance the whole of the suspended matter was intercepted; and of the soluble organic pollution three of the soils examined removed an average amount of 96·5 per cent. of organic nitrogen, and three other soils gave an average of 88·1 per cent. of the same material removed.

Before considering the applicability of this process to practice, it will be important to anticipate what would naturally be offered as an objection to its adoption. It would be reasonable to suppose that, sooner or later, filtration through sand or other material would be interrupted by the pores becoming clogged; but such a conclusion does not appear to be justified by the results, for after passing samples of sewage for three months through one of the filters described, and after "a long series of experiments, there were no symptoms of clogging or diminution of activity, and the effluent water was always bright, inodorous, and nearly colourless."

As a practical conclusion from these experiments the Commissioners give it as their opinion, that "with properly constituted soil, well and deeply drained, nothing more would be necessary than to level the surface and divide it into four equal plots, each of which in succession would then receive six hours' sewage. In this way the sewage of a town of 10,000 inhabitants could at a very moderate estimate be cleansed upon five acres of land, if the latter were drained to a depth of 6 feet."

There is one objection to this process, viz., that the whole of the valuable portion of the sewage is wasted, and such being the case, the process only accomplishes in part the desired object. Notwithstanding this there are situations and conditions that appear almost to justify waste even on as gigantic a scale as this process implies. In localities where land cannot be procured of sufficient extent to employ irrigation, it is possible that downward filtration may be made available and worked successfully. It has been seen that as a rule deodorizing systems are worse than wasteful, for besides giving little or no return, they entail heavy working expenses, and are often very offensive in their operation. When regard is had to the undoubted fact that they do not effectually purify sewage it may be hoped that a substitute will be found in filtration.

Irrigation.

The great preponderance of scientific evidence goes to prove the success of irrigation with sewage, whether it be regarded merely as a mode of abating nuisance on a great scale, or as a commercial speculation. There are, as will be seen, certain authorities, whose opinions and learning are entitled to respect, who take exception to this system; but as against these there is almost the whole weight of experience to decide the matter in favour of irrigation, this process will probably hold its place, until what appear now to be little more than anticipations are to some extent supported by tangible proof.

Before entering on the details of the arrangement of sewage farms, it will be well to dispose of three questions that are suggested at the outset:

1st. Is irrigation an effectual mode of disposing of sewage?
2ndly. Is it prejudicial to health?
3rdly. Is it economical and profitable?

A process to be effectual must provide for the removal of the noxious or putrescible constituents of sewage without creating a nuisance, and must render the effluent water of sufficient purity to admit of its being discharged into the watercourses of the country.

Much difference of opinion exists with regard to this point, some authorities maintaining that absolute purity from organic matter is essential, whilst others contend that, so long as the senses do not detect the impurity, its presence is of little importance; in other words, that water devoid of offensive smell, and that is clear and colourless, is sufficiently pure to be admitted into running water. The Royal Commission, in their recommendations relative to the Mersey and Ribble basins, suggest four standards for determining the purity of effluent water resulting from ordinary sewage, as distinct from that resulting from special manufactures.

With ordinary precautions, irrigation is capable of purifying sewage sufficiently to meet each one of these standard degrees. It is necessary, however, to premise, that adequate care should be taken in the laying out of the surface, of the drainage, and of other matters necessary for successful sewage farming; otherwise, as is the case in some few instances, the purification may be accomplished in part only, and the system thus be brought into discredit.

Taking the instances of Banbury, Warwick, and Norwood, as fair examples of the application of sewage to clay soil, the analyses of the effluent water give for the three towns an average result of organic carbon equal to 1·32 part in 100,000, the quantity of organic nitrogen in the three examples being 0·221 part in 100,000. Taking three favourable examples of irrigation on a porous soil, as Croydon, Penrith, and Carlisle, it is found that the effluent water contains of organic carbon only 0·51 part in 100,000, whilst the average quantity of organic nitrogen in the three instances is 0·146 part in 100,000. Without multiplying examples, these six cases show that irrigation, when managed with reasonable care, removes effectually a sufficient quantity of the putrescible matter to render the discharge of the effluent water into rivers devoid of objection.

In each of these examples, with the exception of Banbury, the whole of the suspended matter is removed. At Banbury, though the management is unfavourable for a high degree of purification, 93 per cent. of the suspended matter is removed, the remaining 7 per cent. probably escaping through fissures in the surface.

It has been said that the purification of sewage is arrested in wet weather, and during prolonged frost. During heavy or continued rain the process of absorption may perhaps be to some extent suspended, but it rarely occurs that rain is so heavy as to flow off the surface of cultivated land; and as this usually takes place when the watercourses of the country are swollen, it follows that any sewage that may be carried away unpurified is so largely diluted as to be innocuous. It will be well for those who regard this as an objection to sewage irrigation to recollect that precisely the same thing may, and frequently does, take place in ordinary farming; manure, it may be, consisting of town refuse, and containing a large quantity of excreted matter, is laid down, and before there is time to plough it into the ground a shower may descend and carry away a great deal of what is very impure into the nearest watercourse. Being, however, largely diluted, this matter passes away without producing injury of any kind. To enter upon the general question here, whether the streams that traverse cultivated and populous districts are to be regarded as fit sources of supply for drinking water, would entail too wide a digression. One fact remains perfectly clear, that if the effluent water from a sewage farm introduces animal organisms or ova calculated to produce specific diseases, the same result may occur from the use of ordinary refuse as manure.

Experiments made to ascertain the degree of purification effected during frost show, that the detergent functions of vegetation are to some extent suspended during a prolonged period of cold; but although the extent of the purification is less than in temperate weather, it is still considerable; and, so far as the investigation has gone, the organic nitrogen in the sewage has not been more than about one-fourth of the amount originally in solution.

In estimating the amount of impurity in the effluent water from a sewage farm, it is necessary to bear in mind that the quantity of the effluent water is much less than that of the sewage that reaches the farm; a large amount of the water is generally absorbed and evaporated in its passage over and through the soil; and, to arrive at a just estimate of the degree of purification actually effected, it is necessary to compare the amount of organic impurity that remains in the effluent water with the quantity of sewage actually arriving on the ground, and not with the amount of effluent water.

The impression that sewage farms are prejudicial to the health of the neighbourhood is fast dying out. In the absence of experience, it would be reasonable to infer that the discharge of a vast quantity of excreted matter over the surface of the ground would produce formidable disease, but that such is not a sound conclusion there is abundant evidence to prove. Even at Edinburgh, where the quantity of land employed for irrigation is disproportionately small, and where it must be admitted the purification of the sewage is in consequence by no means complete, it is shown, so far as a negative proposition admits of proof, that the public health has not suffered in any material respect.

The Author's experience in India, were it not supported by other testimony, shows that irrigation, as practised in that country, affects health to an appreciable extent. The mortality returns of certain districts have furnished proof that the establishment of irrigation works has somewhat increased the death rate, and the same influence is felt in Northern Italy and elsewhere. It must be borne in mind, however, that the systems that produce these results are not similar to the ordinary mode of applying sewage to land. In one case the ground is warped, or completely submerged, for days together, whilst sewage should be suffered only to trickle over the surface for a few hours at a time. A medical authority of eminence[1] holds, that irrigation fields must *prove the medium of propagating entozoa, or parasites, that in* certain stages of development produce formidable disease. This theory, if substantiated by experience, would form a reasonable objection to sewage irrigation, but, fortunately, there is not a particle of evidence to show that cattle fed on sewage farm produce are subject to any special forms of disease. It has for ages, and in all countries, been the practice to use the excretal matter of man and other animals as manure; and surely, if such a custom has not been found to favour the development of parasitic life, no anxiety need be felt that the application of sewage will do so. Let it be admitted, however, for the sake of argument, that these living germs are a source of danger, and there is in carbolic acid a remedy that, used in minute quantity with the sewage, will insure their destruction without in any way impairing the efficacy of the sewage as a manure. After a series of most instructive experiments, the Cattle Plague Commissioners have reported that "the tar acids act most powerfully in arresting all kinds of putrefactive changes, and annihilate with the greatest certainty all the lower forms of life."

In entering upon the third inquiry, as to whether irrigation is an economical mode of dealing with sewage, a variety of circumstances will demand consideration: the cost and the situation of the land, both as regards distance from the town and as to physical position, will first attract attention; it being evident that, other things being equal, gravitation works will have a great advantage, as compared with works in which it is necessary to employ steam power to raise the sewage. The fact of the farm being situated near to, or remote from, a suitable market for the produce to be grown, will also affect the question of economy in an important degree; and it is only by taking all these circumstances into account that the best result can be arrived at. It is not always possible to select land solely with regard to its physical position, for a variety of considerations may present themselves to induce the engineer and his clients to sacrifice something to local circumstances.

It is not desirable to establish a sewage farm to the south-west of a considerable population, as it is from that point of the compass that the winds prevail in this country. Again, it is well to avoid the direction in which building operations are likely to develop; and further, experience teaches that, if corporations hope to succeed

[1] Dr. Spencer Cobbold, F.R.S.

in acquiring land for their sewage, they will act wisely in avoiding collision with influential landed proprietors. The opposition likely to originate with the owners of property does not necessarily arise out of the apprehension that the health of the neighbourhood is likely to be seriously affected; they feel, not unnaturally, that, whether the evil is substantial or sentimental, the value of their property is likely to be prejudiced in the estimation of the public. It is thus evident that the circumstances are, indeed, rare under which an engineer can select the best possible position for his outfall works. It is for him to choose the position least open to objection, rather than that which the simple expediency of engineering practice would suggest.

It is worthy of remark, that in almost every case corporate bodies seek for land in close proximity to their town; and, although this may at first sight appear judicious, it is really in many instances the reverse. The main question that affects the economy of the process is the price paid for the land; and a little consideration will show, that the reduced value of land remote from towns will often more than countervail the extra cost of the outfall sewer; and it may be, and often is, more economical to select land at a considerable distance from, or at a higher level than the district drained, even though pumping should become a necessity. Taking, for example, London, or any large provincial town, it will be found that all the land in the immediate neighbourhood will command high prices for building purposes, whilst at a distance of a few miles an almost unlimited quantity of land may often be secured at little more than agricultural prices.

Reviewing all the circumstances, it is clear there must be a great variation in the results to be obtained in sewage farming as a means of income; and probably the only way to arrive at a sound estimate is to refer to what has already been done, and see what profits have been realized in instances where sound judgment has been exercised. Selecting, for example, Breton's farm near Romford, which receives the sewage of that town, it has been found worth while to pay the local authority the sum of £600 per annum for the sewage alone, or at the rate of about 2*s.* per head of the population that furnishes it. A further sum of £3 per acre is paid for the land, which is a poor gravelly soil, almost unproductive without the addition of large quantities of manure. On this farm the minimum crop is found to sell for £20 per acre, and three or four such crops can generally be secured in the course of a year. All kinds of vegetables have been grown on this farm, realizing in almost every case considerable returns; lettuce, cabbage, and onions, selling respectively for £30, £32, and £46 per acre, and this when preceded or followed by other crops in the same year.

At Lodge Farm, near Barking, the cultivation of ordinary vegetables and cereals has proved equally successful and remunerative; and Italian rye-grass has been produced at the rate of from 60 tons to 70 tons per acre in the year, and sold on the ground uncut for £1 per ton.

A few years ago, it was thought that Italian rye-grass was the only crop that could be raised under the application of sewage; and its wonderful capacity for liquid manure makes it one of the most valuable accessories in the management of a sewage farm, where the purification of the liquid is of the first importance. It is also a most valuable crop, not only as regards the amount of nutriment it contains, but from its coming in earlier and continuing later than almost any other green crop. The use of rye-grass must, however, be limited by the demand for it, and it has been found, in some situations, that there was not a sufficient market to make it as profitable as was hoped. This has been urged as an argument against the adoption of sewage farms with a view to profit; but since it has been discovered that the application of sewage to nearly all vegetables, as well as to cereal crops, is attended with success, the objection is at once removed. It is hardly too much to say that sewage, if it does not accomplish all that farmyard manure will, can be made in its application quite as general. It is not necessary that the land should always be cropped in order that the liquid shall be purified; for whatever the theory of the process may be, it is well known that the soil will of itself take up and store the manurial constituents of sewage to a great extent, and impart them again to the first crop that is grown.

Time will not admit of carrying the consideration of this subject into all the details of sewage farming. Such minutiæ are of the first importance if a high degree of success is to be achieved, but for the present purpose it will be sufficient to consider some of the general principles to be kept in view. Though the services of the engineer will be required for the arrangement of works, the determination of levels, drainage, capacity of conduits, and a variety of other matters, it is evident that his functions become intimately associated with those of the scientific agriculturist, whose co-operation he will, if judicious, avail himself of. Whatever land be selected for the disposal of sewage, it will have to be reformed; it will be necessary to lay out suitable approaches, and the whole farm will, as a rule, have to be under-drained.

At the outset it may be premised that almost any kind of land, if properly treated, will be suitable for the reception and purification of sewage. Existing examples afford ample proof of this fact. At Aldershot, on the Bagshot sands, the soil is perhaps as unpromising as it is possible to conceive, consisting of almost pure silica, resting on a dense layer of peroxide of iron. Without the assistance of sewage this land is practically valueless, but under judicious management it has been let for £20 per acre. At Edinburgh, the soil to which the sewage is applied is simply sea sand that has been drifted above high-water mark, wholly unproductive of itself, but now realizing £25 per acre. Proceeding to the opposite end of the scale, it is found that the stiffest clay soils purify sewage completely. The chemical composition of such soils indeed adapts them for the purification of sewage; and it is remarkable that there is no more general fallacy, than that stiff soils are unsuited for sewage farming. Viewing the soil merely as a chemical purifier of sewage, clay seems to have the advantage over lighter soils; but in practice this is not apparently verified. Plate 19 shows unmistakably the superior purifying effect of the light soil of Beddington over the clay of Norwood.[1] Probably in some instances the comparative excess of organic nitrogen, found in the effluent water at Norwood, was due to some of the sewage escaping through land cracks; but the diagram indicates a perceptible uniformity in the amount of nitrogen at different dates on the two farms, and this can only be accounted for by atmospheric changes, which facilitated or retarded the purifying power of the soil. In stating that any soil may be made available for the reception of sewage, a reservation should be made in the case of low-lying and water-logged ground; such land nearly always produces a certain amount of miasmatic exhalation, and could only be rendered more unhealthy by the addition of sewage. But even this reservation is one that depends on expense, for marshy ground, when thoroughly drained, can be made as available for sewage farming as any other.

Sewage may be utilized with one of two objects in view; first, for the abatement of the nuisance that it would otherwise produce, and secondly, with the design of securing the largest amount of profit that it is capable of furnishing. Whichever of these views prevails will determine the quantity of land required for a given population; as a much less area of land will suffice merely to render sewage innocuous than would be required were it only desired to

[1] Analysis conducted at the College of Chemistry.

turn the manure to the best possible account. Opinions as to the area of land requisite for the disposal of sewage vary within very wide limits, and appear as a general rule to be based upon some empirical mode of reasoning. The sewage of two hundred people has been effectually purified on 1 acre of land at Carlisle, whilst engineers of eminence have stated that the sewage of from five to seven people is sufficient for the manuring of a single acre.[1] The Author's experience is opposed to the application of sewage in small quantities, as the difficulty of distributing the liquid is very great; but much will of course depend on the dilution of the sewage, by wasteful consumption of water, or by the addition of subsoil water.

The experiments on downward filtration, already alluded to, demonstrate the fact that very small areas may, by proper disposal and judicious under-drainage, be made to serve for the purification of sewage, which is the primary object to be aimed at; but it is not therefore desirable to employ the minimum quantity of land that will serve the purpose. To apply sewage to land with economy and profit, it is necessary to secure a sufficient extent of ground. It is obviously impossible to establish an invariable rule for the due proportion of land to a given population; for, in the first place, the composition of sewage in different towns varies within very wide limits; and secondly, the purifying qualities of land will be found far from uniform. Plate 19 illustrates how great is the difference in the purifying powers of the stiff clay soil of Norwood and the free soil of Beddington. Fig. 2 illustrates the quantity of organic carbon remaining in the effluent water as it passes from the land. The dark zigzag bands are plotted from analyses made at intervals of about a fortnight throughout a whole year; and represent the total amount of organic carbon in the sewage on its way to the farm. The lower, or dark one, shows the amount of organic carbon remaining in the effluent water at Beddington, whilst the lighter band shows the proportion of the same impurity found in the effluent water from the Norwood farm. This diagram is only intended to illustrate the relative amount of the impurity removed in each locality. The light shading represents the organic carbon in the South Norwood sewage, which contains 50 per cent. more than the Beddington sewage. For the purpose of comparison, the amount of impurity

[1] Evidence given before Select Committee on the Sewage of the Metropolis, pp. 111 and 117.

in the Beddington sewage is brought up in the same proportion as the organic carbon in the unpurified sewage of Norwood; or, in other words, it is assumed that the Beddington soil would effect an equally good comparative result if it had to purify sewage of the same strength as that of Norwood.

Fig. 1 shows the amount of organic nitrogen in the average sewage of both Norwood and Beddington, and it is remarkable that the impurity should be almost exactly the same in amount in both examples, though there is a wide difference in the respective circumstances of the two places. The upper band shows the amount of organic nitrogen in the effluent water at Norwood, whilst the lower band shows the relative quantity of the same material in the Beddington effluent water. It will thus appear at a glance what a diversity of effect may be produced by different soils. The balance in these two cases is greatly in favour of the free open soil, though chemical theory would seem to indicate a clay soil as relatively the best purifier of sewage.

If it is intended to utilize sewage with a view to profit, there is no guide but experience to indicate how many people of all ages will, under ordinary circumstances, furnish sewage enough for an acre of land. The balance of opinion indicates a proportion of one hundred people, under ordinary circumstances, to 1 acre of average land. It has been seen that the sewage of double this number of persons has been applied to land, and been perfectly purified on 1 acre. No doubt the value of the water alone applied to land is considerable, and a much larger experience, and more careful experiments, alone can determine the area necessary to produce the best result. Regarded as to its manurial qualities alone, however, it appears that when the proportion of as many as two hundred people to the acre has been adopted, the whole of the most valuable part of the sewage was either taken up by the plant, or retained in the soil, the effluent water showing but a trace of nitrogen in any form.

One of the first considerations in laying out a sewage farm will be the mode of distribution to be adopted; and this is a matter upon which there is considerable difference of opinion. The simplest method of distribution is that called catchwork. It consists in cutting on the surface of the land, which must have a considerable slope, a series of distributing channels following the contour of the ground. In this system the water from one channel flows over the surface until it reaches the channel next below it, which acts as a catchwater drain. This channel again allows the sewage to overflow and pass over the surface to the next lower channel, and so on to the bottom of the land. In the simplest kind of catchwork, the lower portions of the farm receive sewage of reduced strength from that discharged on the upper ground; and though it is doubtless desirable, that the quality of the sewage should be as uniform as possible all over the farm, still, if purification be the great desideratum, it is evident that the liquid must be passed over as much of the land, and as frequently, as may be necessary to complete the process. It is not, however, essential in this system that the sewage, when reduced in strength, should be again used; for by cutting a series of carriers at right angles to the contour lines, the sewage can at once be delivered at any level, and be discharged over any part of the surface at pleasure. It is evident that the catchwork system will commend itself on the ground of economy, but it is only applicable in situations where the land is of an undulating character, or presents such an inclination as will admit of a regular, but not too rapid, discharge. If the inclination be too great, the sewage will pass away so rapidly as to leave an undue amount of the fertilizing matter unappropriated by the soil.

The system of irrigation known as pane and gutter is applicable to land having but a slight surface inclination, and is both cheap to carry out and easy to manage. The main carrier is so situated that it will command the greatest possible area, consistent with an inclination that will deliver the sewage to the distributing channels. From this main channel the distributing carriers start, following generally the direction of the greatest fall: from these, again, smaller cuts may be made at right angles, or nearly so, so that the whole has on plan a herring-bone appearance. The smaller distributing channels are laid out nearly level, in order that the sewage when allowed to enter them may be dammed back by boards or stops, until it flows in an uniform stream over the surface.

A third system of surface irrigation is that known as the ridge-and-furrow, or bed system, which is the only one applicable to very level lands. It is more purely artificial than either of the other two, and is the most refined system of surface irrigation practised. The ground is laid out in long rectangular beds; and these are shaped either by the plough or by manual labour, so that the centre line, traversing the crest of the bed, is raised to form a ridge. Along the top of this ridge there is cut a channel having a very gentle slope, and on each side, or in the hollow between two of these beds, there is a channel for the removal of the water after it has passed over the surface. The flow of the sewage in the upper channel is controlled, as in the other systems, by stops of wood or iron, and the sewage flows with perfect evenness over the edge of the channel.

It is hardly necessary to describe here the actual mode of forming the surface in this or either of the other systems. It may suffice to say, that much may be done with the common plough and the subsoiler, though a certain amount of levelling and dressing of the surface must necessarily be performed with the spade. It is not always possible to lay out the beds so that the ridge shall have a perfectly uniform inclination, but this can be met by disposing the carrier in steps, at which points the stops may be placed. The length of the beds in this system is not a matter of great importance, so long as they are approached by a road at either end; though it will be more convenient, and generally cheaper, to restrict the size than to aim at making the beds very large. As regards width and inclination, practice will form the best guide. At Barking farm the largest are beds 150 feet wide, the elevation of the ridge being about 1 foot, which is found to be quite sufficient. At Breton's farm, which receives the sewage of Romford, the owner—after a number of careful experiments, to ascertain what was the best and most convenient width of bed—has determined on adopting 30 feet. "This breadth combines other great advantages not connected with irrigation; for the area of a bed is at once obtained in square yards by multiplying the length by 10. This for selling market garden crops is of very great convenience."[1] Besides the convenience of narrow beds, they possess the advantage of being more cheaply formed, and effect a marked economy in the disposal of the sewage.

The rules laid down by some of the best French authorities on irrigation as practised in France and Belgium are, that the minimum slope of the surface shall not be less than 1 in 125, that the greatest inclination *may* be 1 in 3½, and that slopes varying from 1 in 10 to 1 in 33 will be found the most convenient in practice.[2] It is not possible to establish any general rule for the laying out of irrigation ground, so long as engineers have to deal with land

[1] "Lecture on Sewage Irrigation, delivered by W. Hope, Esq., to the Ratepayers of West Derby," p. 14.

[2] "Irrigations, Engrais Liquides et Améliorations Foncières permanentes." Par M. Barral, p. 402.

Vide "Manuel d'Irrigation." Par M. Jules Deby, p. 81.

varying in quality and inclination; each case must be treated according to circumstances by one of the foregoing methods, and more in accordance with the existing features of the surface than by any general rules.

Until recently the usage has been to distribute sewage in open carriers or cuts on the surface of the ground; but from their irregularity, and from the constant soakage into the soil, these channels were always more or less offensive. Now, however, when any degree of refinement is aimed at, carriers of iron, earthenware, or concrete are used, which necessarily discharge the sewage without leaving any considerable portion to adhere to the sides, and cause foul smell. Plate 20 shows a variety of carriers adopted in different localities, including the wrought-iron carrier supported on wooden trestles, as used at Breton's farm.

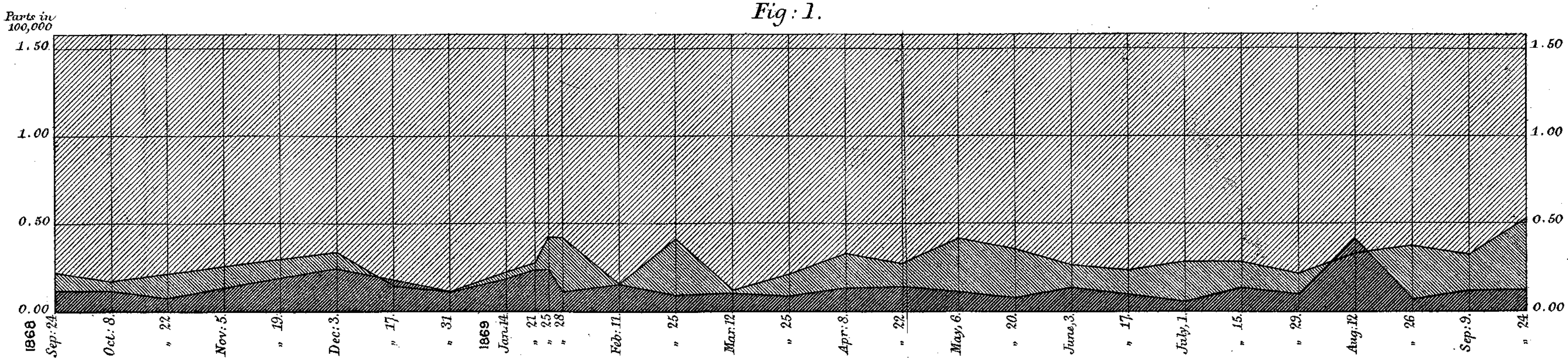
It is not proposed to discuss here either the method of subsoil irrigation or that known as the hose-and-jet system. The first of these is beset with disadvantages, and the second is inapplicable on a large scale. In many instances the hose-and-jet plan has been practised with great success and profit, but it would be found unmanageable and expensive on such a scale as the application of the sewage of towns and cities necessarily involves. The ruling maxim in applying sewage to land is, that the works of distribution shall be simple and easily controlled—a principle that hardly applies to either the hose-and-jet, or the underground system of irrigation.

A point worthy of consideration in applying sewage to land, is the degree of filtration that it is desirable to submit the liquid to before allowing it to flow into the channels. A variety of insoluble matters are to be found in all sewage, and a large proportion of the whole will consist of solid excreta. This portion, which is really the most offensive to the senses, contains only about $\frac{1}{7}$th part of the fertilizing material. It is usual, in ordinary practice, to allow almost the whole of this to leave the outfall, and distribute itself over the surface of the ground, or, rather, adhere to the sides of the carriers, but the expediency of such a course is questionable. Where the farm is remote from dwellings, no great inconvenience will arise from exposing a large amount of offensive matter on the surface of land, where before long it becomes deodorized by exposure to the air and soil; but in situations contiguous to dwellings it will certainly be desirable to arrest a considerable part of the solid material, and afterwards apply it as ordinary manure to the ground, or to dispose of it for what it will return, which as a general rule is not a large sum. At Norwood, where most of the ordure is removed by upward filtration, the material is mixed with burnt clay and used for filling up hollows in the surface of the ground; and at Ealing the entire of the solid matter resulting from a population of nine thousand five hundred is mixed with ashes and disposed of for about £75 per annum.

If it be desired to employ sewage without creating prejudice and distrust, it is most desirable that it should be clarified to a considerable extent; the loss is but trifling, and avoidance of all nuisances is certain.

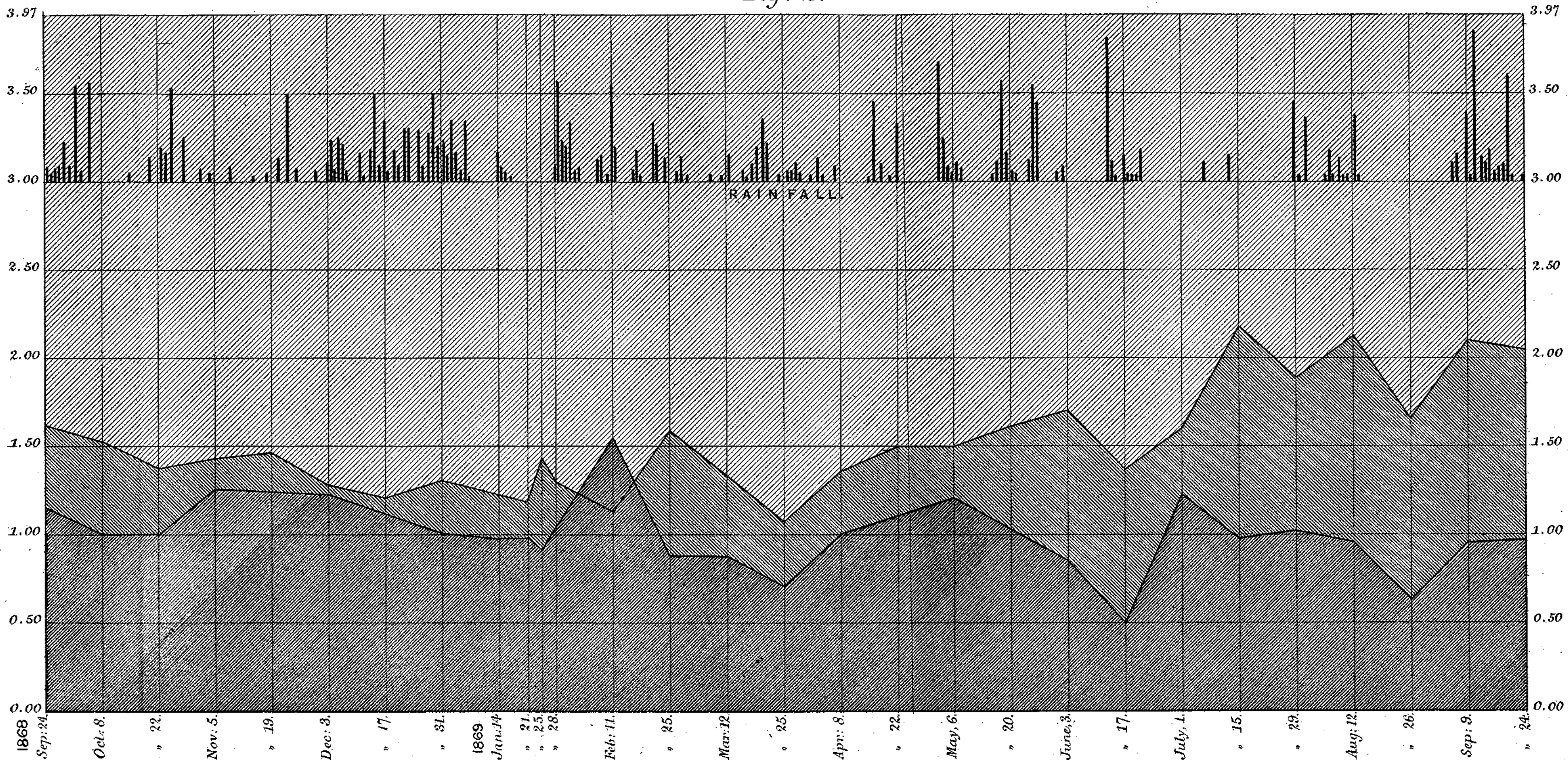
The communication is accompanied by a series of diagrams, from which Plates 19 and 20 have been compiled, and by several Tables, containing further detailed information, which are appended.

Fig: 1.



ORGANIC NITROGEN IN THE SEWAGE OF NORWOOD AND BEDDINGTON.

Fig: 2.

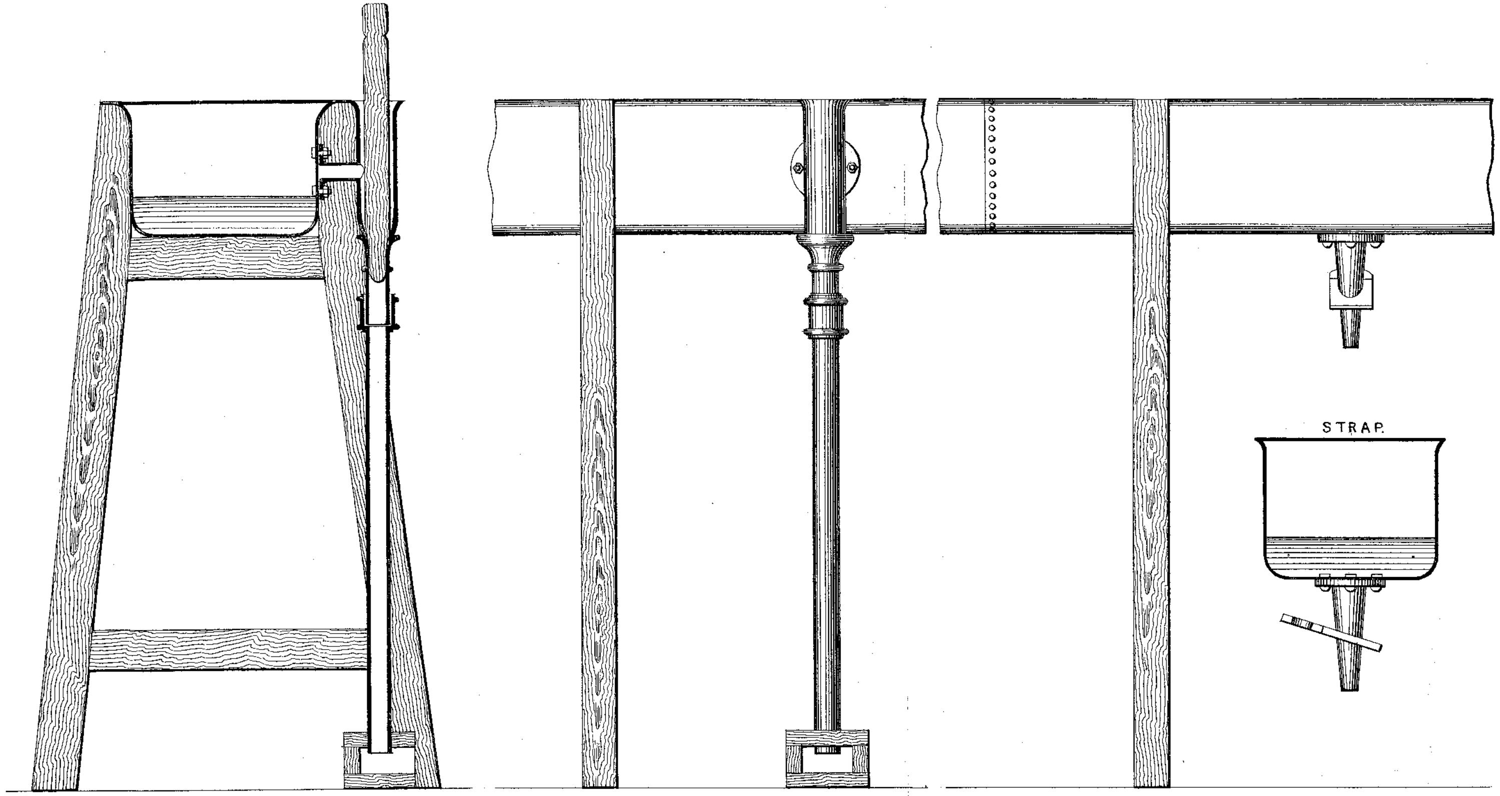


ORGANIC CARBON IN THE SEWAGE OF NORWOOD AND BEDDINGTON.

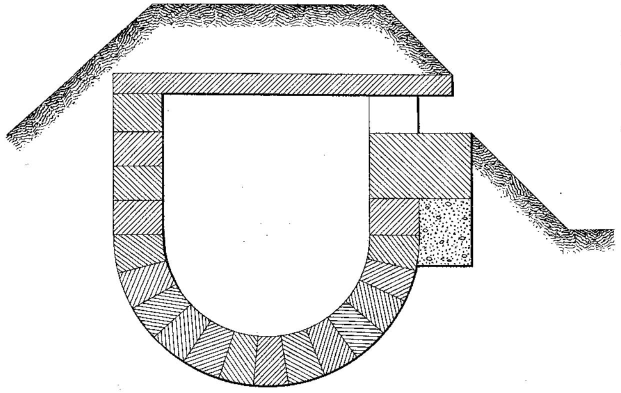
NOTE
The vertical measurements on the Scale of rainfall are equal to the depths that fell on each day.

A. JACOB, DEL^{T}

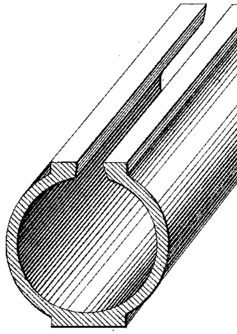
KELL, BRO^{S} LITH^{RS} CASTLE S^{T} HOLBORN.



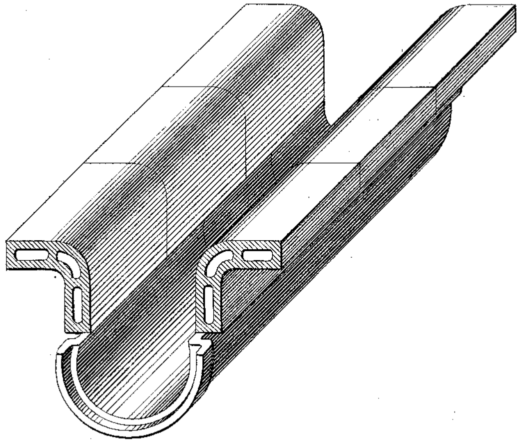
SECTION. IRRIGATION CARRIER USED AT BRETON'S FARM, ROMFORD. ELEVATION.



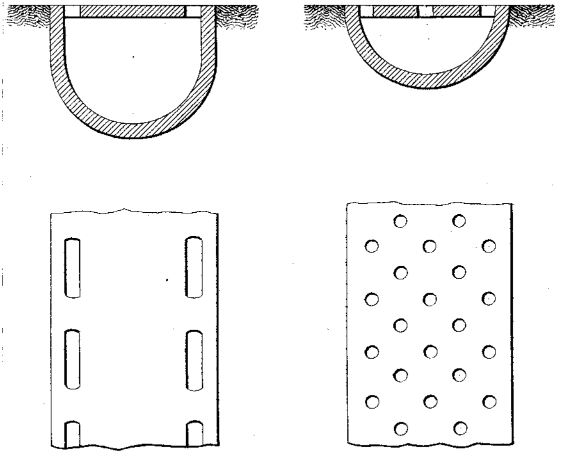
REDHILL.



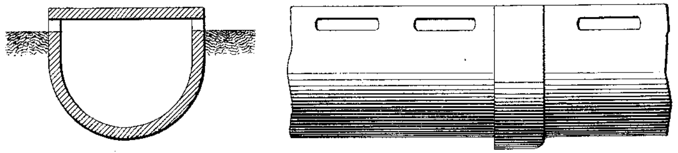
REDHILL.



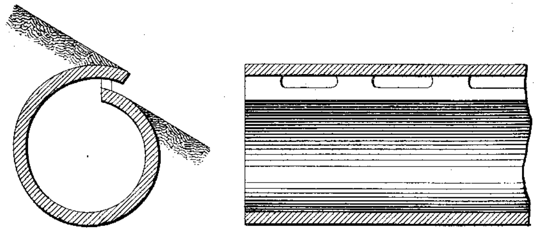
DOULTON'S SEWAGE CARRIER.



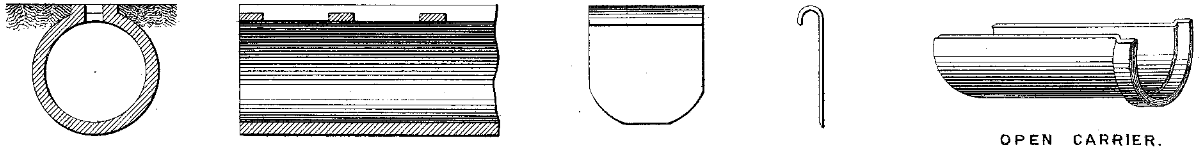
NORWOOD.



NORWOOD.



READING WORKHOUSE.



OPEN CARRIER.

APPENDIX.

TABLE 1.

—	Organic Carbon.	Organic Nitrogen.	Insoluble Matter.
CHEMICAL.			
The Lime Process.			
Best	36·1	65·8	96·8
Average	27 7	43·7	80·6
Worst	23·4	10·4	59·6
The A B C Process.			
Best	34·8	58·9	96·0
Average	32·1	54·3	92·0
Worst	25·8	50·1	87·4
The Northampton Process . .	50·1	37·1	99·8
MECHANICAL.			
Downward Filtration.			
Through sand, 5·6 gallons per cube yard in 24 hours.			
Best	84·9	96·9	100·0
Average	83·3	95·6	100·0
Worst	81·1	94·5	100·0
Upward Filtration.			
Through sand, 3·6 gallons per cube yard in 24 hours.			
Best	50·7	65·5	100·0
Average	26·3	43·7	100·0
Worst	00·6	12·4	100·0
IRRIGATION.			
Bedford light gravelly soil.			
Best	78·9	97·4	100·0
Average	71·6	81·3	100·0
Worst	60·5	70·8	100·0
Norwood clay.			
Best	76·1	92·0	100·0
Average	65·0	75·1	100·0
Worst	51·3	44·1	100·0

TABLE 2.—Localities where Chemical and Mechanical Processes are employed.

LOCALITY.	Number of Inhabitants Contributing Sewage.	Cost of Purifying Works.	Annual Outlay for Working.	Mode of Purification Employed.	Annual Return from the Sale of Manure.	Remarks.
Alton	3,000	£800	£55	Lime and perchloride of lime.	Nil.	
Canterbury	11,000	£2,000	£125	Charcoal	£15	A larger profit anticipated.
Ealing	9,500	£3,000	£300	Filtration through sand and charcoal with deodorization by tar and lime.	£75	It is estimated that the cost of these works is 50 per cent. higher than if they had been constructed in excavation.
Hastings	25,000 to 30,000	£5,000 to £6,000	£3,000 to £3,500	A B C process, Sillar's patent.	28 tons of manure produced per week, and said to be sold at £3 10s. per ton.	Particulars furnished by the Secretary to the Company.
Luton	8,000	£3,000	£470	Higgs's patent (milk of lime).	£65	A much greater return expected.
Northampton	30,000	£6,000	About £500	Sulphate of iron, alumina and lime, perchloride of iron, and alumina.	£490	This process is about to be abandoned for the ordinary lime treatment.
Uxbridge	6,000	£2,000	£180	Filtration through charcoal.	£25	Charcoal changed every 6 weeks in summer.
Worksop	8,650	£5,800	£37	Lime process	£38	

TREATMENT OF TOWN SEWAGE.

Localities where Irrigation is pursued.

Name of Locality.	Number of Persons whose Sewage is applied.	Number of Gallons per Head Daily of Water Supply.	Surface Water combined with the Sewage or not.	Suspended Matter, how separated.	Mode of Distribution.	Character of Soil.	Distance of Land from the Population.	Kind of Crops Grown.	Condition of Effluent Water.	Profits arising from the Application of the Sewage, all Expenses being allowed for.	Area under Cultivation.	Land Underdrained or not.
Cheltenham	40,000	25	Yes	Separated by rough filtration and depositing.	Open carriers . .	Clayey	2 miles	Grass	Very satisfactory, though not perfectly pure.	None at present.	130 acres.	Underdrained.
Leek, Staffordshire . . .	11,300	24	Yes	Not separated . .	Open carriers . .	Sandy subsoil . .	2,245 houses are within 440 yards of the farm.	Mostly grass . .	Nearly pure . . .	None. The sewage is given to the landowners.	145 acres.	Not underdrained.
Beddington	40,000	40	Yes	By Patent Sewage Extractor.	Open carriers . .	Light soil, resting on a gravel subsoil.	$\frac{3}{4}$ of a mile . . .	Rye-grass, mangold, &c.	Pure	£1 per acre, or £260 per annum net profit.	260 acres.	Partly underdrained.
Norwood.	4,000	..	Yes	Sewage filtered upwards through burnt clay.	Covered earthenware carriers.	Clay	400 yards from thickly inhabited district.	Rye-grass and vegetables.	Pure	About £4 15*s.* per acre net return.	30 acres.	Formerly underdrained; the pipes had to be removed.
Carlisle	22,000	Not ascertained.	Yes	Not separated . .	Movable iron carriers.	Alluvial soil, on a bed of gravel.	$\frac{3}{4}$ of a mile . . .	All grazed . . .	No effluent water visible; subsoil water pure.	Leased for 15 years at a nominal rent of £5 per annum.	100 acres. .	Not underdrained.
Rugby	7,800	25	Yes	By strainers . . .	Open carriers . .	Loam with clay and gravel subsoil.	1 mile	Rye-grass and mangold.	Pure	£80 per annum	65 acres.	Underdrained.
Barking	..	..	Yes	By a settling tank .	Open carriers . .	Gravelly. . . .	.. ..	Rye-grass and all kinds of vegetables.	Pure	Return calculated at 5*s.* per annum for each person contributing the sewage.	.. ..	Underdrained.
County of Durham Lunatic Asylum.	503	25	No	Not separated . .	Hose and jet. . .	Free loamy soil . .	50 yards	Garden crops of all kinds and grass.	No effluent water apparent.	Expenses nil; profits from £100 to £200 per acre on vegetables, and £20 to £29 on grass.	32 acres.	Partly underdrained.*
Somerset County Lunatic Asylum.	550	50	$\frac{1}{4}$ of the rain falling on roofs and yards passed into sewers.	Not separated . .	Open carriers . .	Dolomitic conglomerate.	130 yards . . .	Cabbage, mangold, and Italian rye-grass.	Water all absorbed .	Expenses nil; cabbages weigh from 56lbs. to 70lbs., mangold 17lbs. to 23lbs.	18 acres.	Partly underdrained.
Broadmoor Lunatic Asylum	600	40	No	Sewage filtered through charcoal.	Carriers	Soil and subsoil gravel and sand.	130 yards . . .	Vegetables and rye-grass.	.. ..	Expenses about £25 per annum.	19 acres.	Underdrained.
Romford	7,000	..	Partly combined .	By strainers . . .	Open carriers . .	Poor gravelly soil .	2 miles	Vegetables, flowers, and grass.	Water clear and apparently wholesome.	Return not known; crops excellent.	121 acres.	Underdrained.
Aldershot	7,000 adults.	22	No	By subsidence and filtration.	Open carriers . .	Poor sandy soil . .	$1\frac{1}{4}$ mile from the south camp.	Rye-grass and vegetables.	Nearly pure . . .	Crops excellent; some of the land let at £20 per acre to cowkeepers. Estimated return 3*s.* 4*d.* per head of population.	113 acres.	Partly underdrained.

* Part of the Durham Farm was formerly a wet, low-lying, cold, heavy field, which was underdrained; the remaining portion light soil on light sandy bottom. The crops on the former are decidedly the heavier of the two.