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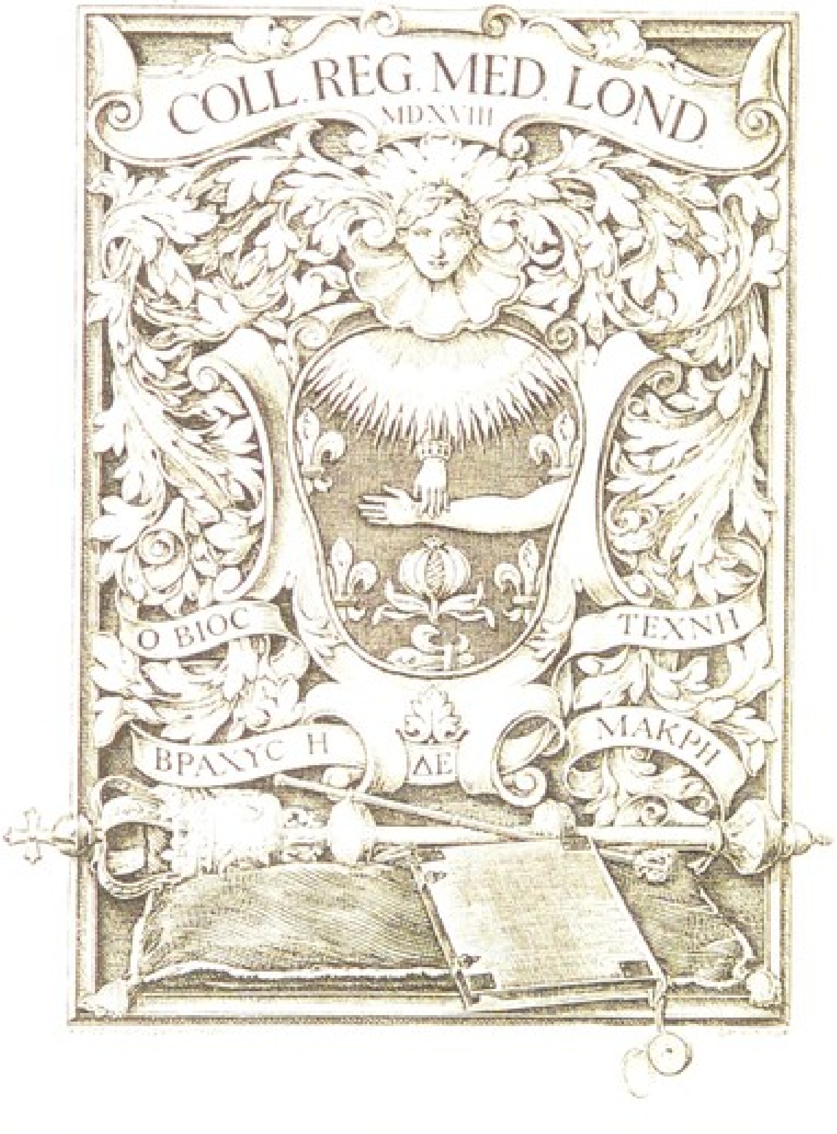
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THE TREATMENT

AND

UTILISATION OF SEWAGE

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UTILISATION OF SEWAGE

BY

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THIRD EDITION, REVISED AND ENLARGED

BY THE AUTHOR

AND

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Μηδέ ποτ' ἐν προχοῃ ποταμῶν ἅλαδε προρεόντων,
Μηδ' ἐπὶ κρηνάων οὐρεῖν, μάλα δ' ἐξαλέασθαι,
Μηδ' ἐναποψύχειν· τὸ γὰρ οὔτοι λώϊόν ἐστιν.

HESIOD, *Works and Days.*

PREFACE TO THE THIRD EDITION

As it is now sixteen years since the second edition of this work was published, and as a large amount of additional experience has been gained in the interval, I thought it desirable to issue a new edition, and was so fortunate as to secure the co-operation of my friend and former pupil, Dr. Louis Parkes, with whose valuable assistance the work has been in great part rewritten and very considerably enlarged.

The historical portions have been retained in their entirety, as being not only interesting in themselves, but also, on the one hand, descriptive of a state of things still to be found in many places, and on the other, important as a record of methods and processes which have been adopted at various times. It must be remembered that methods and processes which have been tried and abandoned as useless, are liable to be brought forward again as new at some future time, unless such a record is kept.

The important investigations of the British Association Sewage Committee — more especially as regards the determination of the percentage of the manurial ingredients of sewage actually utilised by irrigation on land, and recovered in the form of crops; the accurate method devised by that Committee for taking samples of sewage and effluent water for analysis; the practical inquiry originated by the suggestion made by the late Dr. Cobbold that entozoic disease might be spread through the agency of sewage farming; and the quantitative examination, with a view to its manurial value, of the compost resulting from the use of earth closets—which have not hitherto received the attention they deserve, are described in detail.

Some matters of special interest, such as the Treatment of Manufacturing Refuse, and the Disposal of the Metropolitan Sewage, which could not be conveniently included in the body of the work, and also some points connected with Precipitation Processes now in use, which have been investigated whilst the work was passing through the press, have been inserted in the form of an Appendix.

W. H. C.

19 Savile Row, W.

EXTRACT FROM THE PREFACE TO THE SECOND EDITION

The first edition was, as stated on its Title-page and in its Preface, prepared for the British Association Committee, appointed at Exeter in 1869 to report on the "Treatment and Utilisation of Sewage;" it was published after the Report of that Committee had been read at Liverpool, and it was in no sense their Report, nor were they in any way responsible for its contents or bound by the conclusions arrived at; for whilst the facts brought forward rested on the authority of the documents quoted, the writer distinctly claimed for himself the sole responsibility "for the conclusions drawn, and for the opinions expressed."

It was, nevertheless, thought by some members of the Committee appointed at Liverpool in September 1870, that if the second edition were published under the auspices of the Committee they might be considered to be bound by the opinions and conclusions therein contained, or at any rate to have sanctioned them.

Under these circumstances the Author has thought it advisable to publish this edition entirely on his own responsibility, and so prevent any misunderstanding about the matter.

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LIST OF ABBREVIATIONS

H. of T. C.	Health of Towns Commission.
S. of T. C.	Sewage of Towns Commission.
M. O. P. C.	Medical Officer of the Privy Council.
L. G. B.	Local Government Board.
R. P. C.	Rivers Pollution Commission.
B. A.	British Association.

THE

TREATMENT & UTILISATION OF SEWAGE

CHAPTER I.

EARLY SYSTEMS: MIDDEN HEAPS AND CESSPOOLS

OUR subject matter falls conveniently under two heads: we have to consider, in the first place, the *Treatment* of Sewage, which resolves itself into various methods for *removal* of it from the neighbourhood, either in its native state or mixed with some substance which may facilitate its removal, as water; or may render it less disagreeable, as dry earth, ashes, salts of carbolic acid, salts of iron, etc.; this removal being necessitated by the extremely *offensive* nature of excrement when allowed to remain for any length of time in or near houses, of which no one will require proof (although plenty will be incidently given in these pages), and also by the great *injury to health* which results in various ways from the same cause, and of the reality of which we have now ample evidence.

Divisions of subject.

Removal.

And, in the second place, we have to consider the *Utilisation* of Sewage. We have to examine the evidence that has been brought forward to show that

Utilisation.

the various refuse matters from human habitations may be applied as manure, with advantage to the crops and profit to the community, and at the same time without nuisance or injury to the neighbourhood: we have to see which of the various methods proposed offers the greatest chance of success in a sanitary, an agricultural, and a pecuniary point of view.

Definition of term "Sewage."

The term "Sewage" will for convenience be applied generally to refuse matter (especially excretal) without reference to any method of removal; and this it is necessary to bear in mind, as no scheme which does not remove ALL refuse matter, in as inoffensive a manner as possible, and utilise it to the best advantage, can be accepted as anything like a final solution of the question that we have to study, nor can such a scheme be recommended to towns as a feasible plan for the removal of their difficulties.

Under our first head, then, we include the *collection* and *removal* of refuse matters, and more especially of human excreta, from habitations generally, and more particularly from collections, large collections, of habitations.

We begin with the deposition of excreta, and the places in which they are deposited.

No system.

In the primitive condition of society no consideration was given to these matters, and no special places allotted at all for such purposes, and of course the result was, that excrement was deposited in any convenient or inconvenient locality: and we have to allude to such a primitive condition of things because it is not confined to some distant period, or to what we are pleased to call barbarian countries, but exists to-day in many of our own towns. In the Fourth Report of the Medical Officer of the Privy Council, dated 1861, we find, with regard to one place, that "in the great majority of cases, even *in the centre* of the town, no accommodation of any kind is provided, and hence the adult male population defecate habitually in the gardens or in the road," etc.; in another town "children's excrement and other refuse are frequently allowed to remain dotting the space before and behind houses." In the Seventh Report (1864) we find that at Seacroft "it is the practice to throw everything in the shape of sewage, garbage, refuse, and even solid excrement, into the highway, on to the green or the adjacent midden heaps, or into a ditch if such be handy." In the colliery settlements at Gilesgate Moor the roadway is described as a succession of dust-heaps used "for all purposes of personal easement." From the Ninth Report it appears that until comparatively lately (1854), houses under £10 rental were not provided with privies or cesspools, the inhabitants using the open streets instead; and even in 1864 "many houses and courts are unprovided with any accommodation, and stools are seen about yards and entries;" while at Penzance the filth from the upper stories of the houses was commonly discharged into the court or passage below.

Want of privies.

In the Health of Towns Report of 1844 (vol. i. p. 128) Dr. Duncan states that the whole of the cellar population of Liverpool, amounting to more than 20,000 persons, "are absolutely without any place of deposit for their refuse matter," while "of the front houses inhabited by the working classes, a large proportion are in a similar predicament."

A place set apart for refuse matter.

As a slight improvement to this loathsome state of things, we come to the setting aside of a special locality where the refuse matter of one house, or often of many houses, may be deposited—in other words, a "midden heap;" and "occasionally a wooden erection may be seen, having the external aspect of a privy, and used as such, but with only a cross bar or plank for a seat, and *no cesspool whatever*, the excrement being allowed to accumulate there and diffuse itself thence for an unlimited time, or until it is required for manure." (*Fourth Report of Medical Officer of Privy Council*, Appendix, p. 38.)

Open midden pits and cesspools.

More frequently, however, some sort of a pit is dug in the ground and serves as the receptacle of filth generally; this is open to the air and without any pretence of drainage, and is known as a "midden" or "ash-pit," or, if used for excrement alone, as a "cesspool:" such pits are in gardens, yards, or courts, surrounded on all sides by houses, and are used by many houses, there being one or two "necessaries" for the use of many families. Thus "in each of the larger courts* there are usually two privies, with an ash-pit between them, situated within 3 or 4 feet of the doors and windows of the houses at the upper end, and *which are the common property of all the houses in the court*. These offices are often in such an abominably filthy and ruinous condition as to make it a matter of wonder how they can possibly be used; the ash-pits are entirely uncovered, and the door of the privy is sometimes absent, having been broken or become dilapidated from age. In many instances the inhabitants of the front houses and cellars make use of the conveniences in the courts, so that the ash-pits generally become full to overflowing long before the nightmen make their appearance to empty them." (*Dr. Duncan's Report on*

* Containing sixteen houses and a population averaging 80 persons.

Liverpool in First Report of Health of Towns Commission, 1844, vol. i. p. 128.)

Dr. Trench, too, says: "Not only was space economised at all risks, and the built-up area dreadfully overcrowded, but privies and cesspools were placed inside houses and in other improper situations; while courts, terraces, and blocks of back-to-back houses, occupied by numerous families, were insufficiently supplied by a common latrine, with a deep, wide, open, and undrained cesspool." (*First Report of the Rivers Pollution Commission*, 1868, vol. ii. p. 302.)

One privy for many houses.

The extent to which this want of convenience has been carried may be judged of from the state of some parts of Manchester in 1845, when it was reported by the superintendent of the nuisance inspectors that "there were 645 houses in the neighbourhood of Oldham Road and St. George's Road, with families of eleven persons on an average, making an aggregate of 7095 persons, having only thirty-three petties (necessaries) for their convenience, which, as might be supposed, are generally in a most disgusting and filthy state;" while in another district "there are very few privies throughout the neighbourhood, three or four streets having no accommodation of that kind whatever." (*Second Report H. of T. C.*, vol. i. p. 370.)

Under this head must be included stagnant ditches, which are used as open cesspools, as at Steyning, where Dr. Whitley reported that the drainage was into two open ditches, and that privies with open cesspools were general, there being sometimes six families to one privy; in one case, that of a very old cottage, the privy was against the outer wall adjoining the fire-place of the only sitting room and the end of the pantry.

In Leicester, in 1849, "the number of uncovered soil-pits receiving the soil, dust, and ashes, amounts to 2900, and the aggregate surface of the said soil-pits exposed amounts to $1\frac{1}{4}$ acres." (*M. O. P. C.*, 1866.)

Open cesspools at various towns.

At Penzance and other places the open cesspools were often flooded by showers, so as to overflow into the gutters of the courts; while at Warwick the practice used to be to dig a pit in the sandstone rock beneath the courtyard of the house, and throw all refuse into it; thence the liquid parts sank into the surrounding soil. It seems that there were in this town 1516 cesspools, exposing an open surface of "37,000 square feet of fæcal matter to sun, wind, and rain."

At Rugby the open cesspools, which were from 5 to 10 feet long, from 3 to 8 feet broad, and from 4 to 5 feet deep, were lined with brick below the surface: into them all the refuse was thrown, the privy being placed at one end; where much ashes were thrown in they were rendered less offensive; but where little ashes could be got, as in the tenements of the poor, the "stench was intolerable and loudly complained of." While at Pill, near Bristol, Dr. Buchanan reported in 1866 that either the privy seats jutted over the edge of the river, "or that there was an open privy pit, great ponds of seething filth lying behind the privy."

As an extreme example of want of removal of refuse matters we may refer to a case described in the Second Report of the Health of Towns Commissioners (1845): "In consequence of the confined space the privy and ash heaps were accumulated in the cellars.

Commonly the excuse for closed doors and windows was the bad smell of the court; but here I found a special contrivance for keeping open the outer door, without which the tenant said 'she could not bide in the house . . . the stench at night was sometimes past bearing, especially in rainy weather.' But the *rent was low*, 1s. 9d. per week for three rooms, *on account of the nuisance.*

Midden heaps in cellars.

"The cellar accumulation often overflowed, for 'it was such an awkward place, the farmers did not like the trouble of fetching it out,' and the landlady had sometimes been induced by the tenant's complaint to pay for its removal." (Vol. ii. p. 84.)

State of courts, etc.

The report just quoted abounds in examples of a similar state of things taken from various towns: "narrow and enclosed courts, with tunnel entries, most of them with the midden and privy heaps in a most pestilential condition;" "the upper end of the yard I found to be a receptacle for every kind of filth, and it was used as a privy by the inhabitants," etc.

Of the state of the courts in Whitechapel in 1844 we find the following statement made: "Usually in the courts there is only one cesspool; they are badly cleansed; often overflowing. The effluvium is most offensive and noxious. In many of the houses the privy is in the cellar. In one of the courts in Essex Street, now pulled down, the privy was within three yards of the door of one of the houses, and the soil was lying outside of the privy door." (*First Report H. of T. C.*, vol. i. p. 107.)

COVERED CESSPOOLS.

After the open midden heaps, ash-pits, and cesspools, we have the ordinary form of covered cesspool, a pit lined with brick or stone work, or merely dug in the ground and roofed over in some way. These receptacles, often of very large size, are placed under gardens, yards, courts, streets, and even houses, and usually, even when lined with masonry, allow the liquid part of their contents to percolate into the surrounding soil; indeed in many cases they are so built as to assist this escape in order that the solid contents may remain in a drier and comparatively less noxious state. Thus it is not to be wondered at that "the fluid contents of the overcharged ash-pits too frequently find their way through the mouldering walls which confine them, and spread a layer of abomination over the entire surface of the court;" while "in some instances it even oozes through into the neighbouring cellars, filling them with its pestilential vapours and rendering it necessary *to dig wells to receive it* in order to prevent the inhabitants being inundated;" it being added that "one of these wells, 4 feet deep, filled with this stinking fluid, was found in one cellar under the bed where the family slept." (*First Report H. of T. C.*, 1844, vol. i. p. 128.)

Percolation from cesspools.

In Bedford, in 1860, it was reported that cesspools were "almost universal," there being more than 3000 of them, and as they were not allowed to drain into the sewers (!) the liquid matters soaked away from them as fast as possible into the surrounding soil. At King's Langley, Dr. Ord had four large cesspools opened, each being 3 feet square and 4 feet deep; they were placed under the pathway, and supposed to be for surface water. Two of them were found to contain dirty water, with some inches of black mud; one only black mud 20 inches deep; and the fourth was "filled with sewage, soft, solid, and of

Contents of them.

a most offensive character, the drains of five or six houses being led into it." At Seacroft, Dr. Stevens tells us that "on lifting one of the flags in the sitting-room (of a cottage) two buckets of sewage were found under the floor." At Alnwick we learn that in 1849 there were "large middens, foul privies, and cesspools crowded among houses originally built much too close, privies and cesspools within dwelling houses and under the floors of sleeping rooms;" and again, "in all sorts of corners and confined spaces in contact with the walls of dwelling-houses, and in some instances above the level of their floors." In another town we find that the privies attached to the cottages of the labouring classes, with their attendant cesspools, are situated just under the back windows, while "surface drains are not unfrequently used to carry away the sulliage from the overflowing cesspools."

Bad positions of.

And to show that cesspools were not at all confined to the lower classes of houses, and that they were sometimes as badly placed in fashionable quarters, we may state that in Dover they existed "under many of the best houses." (*Fourth, Seventh, & Ninth Reports M. O. P. C.*)

But it is not at all a thing of the remote past, this covered, undrained cesspool. Dr. Trench, in his report on the *tunnel middens* of Liverpool, in 1863, thus describes the locality known as Kent Terrace, of which he remarks, that "although far from being the worst of the kind, it presents a tolerably average picture of the contrivances adopted in these terraced houses." (*First Report R. P. C.*, 1868, vol. ii. p. 302.)

Tunnel middens at Liverpool.

It "is bounded and enclosed on the west by the front houses of the street; on the north and east by a high wall; on the south by oil-mills. The entrance is a passage 15 feet in width; thus, though not ranked as a close court, it is without any thorough ventilation. Here ingenuity has accumulated seventy-six houses, containing, at the period of inspection, families consisting of 529 souls, on a superficial area of 2346 yards. Beneath these houses are tunnels of the following dimensions: viz. one under the south side, 160 feet in length by 6 feet 4 inches in height and 3 feet in width; one under the north side, 145 feet in length by 6 feet 4 inches in height and 3 feet in width; one under two ranges of houses in the centre terrace, 135 feet in length by 6 feet 4 inches in height and 3 feet in width. The total area thus occupied by middens is 192 superficial yards; their cubical contents 384 yards. In other words, the area of the middens is to the whole area of the ground occupied as 1 to 12·2; the area of tunnel and middens is to the area occupied by buildings as 1 to 9·25. A rough estimate given by a competent authority of the contents of these middens before thought full enough for emptying, is 225 tons. The only exit for the gases of this vast accumulated sewage is through privies, which in the centre terrace are so placed between two lines of double-terraced houses that effluvium constantly and necessarily pervades every room of the building; and in the side terraces on ledges abutting on sleeping and inhabited apartments, where the like noxious effect is unavoidably obtained. The rain, as well as all the water escaping from taps or used for household purposes, find their way into the tunnels, so that at every period of the day there is disturbance of contents, which stimulates the escape of the gases. No breath of air can reach the unhappy residents which is not fraught with offensive

Escape of foul air from.

and deleterious compounds; no fire can be lighted in any household without attracting the influx of pestiferous miasma."

The thoroughness of this description must be our excuse for quoting it *in extenso;* the sanitary evils of such a state of things we shall have to treat of in another place.

In other towns.

In several towns, as at Preston, Leeds, and Birmingham, such huge midden-pits still remain in an almost unimproved condition; they are sometimes covered and sometimes provided with drains, but are usually foul and stinking to the last degree; the liquid soaks out of them to a considerable extent, and pollutes the surrounding soil; in the last-mentioned town they are frequently under workshops, and in all they are emptied very irregularly (1872).

At Halifax there are rows of privies in passages between parallel streets, with a long ash-pit under each row; many of them simply drain into the porous millstone grit. There is a charge of 1*s.* 4*d.* to 2*s.* a cubic yard made by the authorities for emptying them, so that it is usual to make them large and leave them a long while too full (1872).

A curious example of the large undrained covered cesspool is described in the Indian Sanitary Report for 1870 (p. 151), as existing at Belgaum, in the Bombay Presidency.

Latrine caverns.

There are no public latrines, but a curious system of latrine caverns or pits in the courtyard of every family, excavated to a considerable depth, platformed over, the whole generally covered with a tiled hut. These latrine caverns have existed from time immemorial, and are said to number 2240. The arrangements for removing the soil, if any, seem very defective. Though the water supply is abundant, the wells are often situated in close proximity to these latrine pits.

The police were located in wretched dilapidated huts, surrounded by open cesspits, with no provision for drainage. The whole ground in and about the lines pregnant with abomination.

And this with a mean temperature of 74°·42 Fahr.; yet, "as usual at Belgaum, there was comparative immunity from fever," and a table is given showing "that Belgaum has long possessed a reputation for salubrity." The reason for this is doubtless to be found in the fact that "the town is laid out with some regularity, and the principal streets are kept in good order," while the native dwellings are said to be clean inside, although "the exteriors and surroundings are very foul."

Reasons for salubrity.

PERCOLATION INTO SURROUNDING SOIL.

The soakage from all these forms of open and closed cesspools, etc., into the surrounding soil has been referred to. Sometimes, as at Guildford, where they are sunk into chalk, this takes place to such an extent that they are actually stated to be "dry and inoffensive," and the frequency with which they need to be emptied of their contents depends of course upon their size and upon the rate at which the liquid parts soak out of them. Thus in Bridport they were sometimes not emptied "for a dozen years or more," at other places "once in two or three years," "at uncertain intervals," "at intervals of several years;" at Rugby "the solid parts accumulate for many years;" in Penrith "some cesspools have not been emptied for twenty years," even now (1866) the midden system is in favour there, and "in practice, middens are kept till they are full or till it is worth a farmer's while to buy their contents." While, as a crowning success to the percolation system, at Northampton the cesspools were pits dug in spongy sandstone, and were "made and closed for ever;" they were said to be hardly

Not emptied for long periods.

Northampton plan.

ever cleaned out, and always nearly empty! "It is a principle with the Northampton builders that a cesspool needs no drain, so absorbent is the sandy stratum." (*Seventh and Ninth Reports M. O. P. C.*)

In one report we find it stated that the mischief which arose from the privy and cesspool system is due to the moisture of the contents, that the privy, if dry, is "unobjectionable," and that the dryness may be secured by mixing the ashes with the ordure and by adding an occasional spadeful or so of dry earth; and this naturally brings us to consider what becomes of the liquid part of the refuse in all the foregoing arrangements, in which no attempt is made to retain it, and in some of which, as we have seen, its escape is facilitated as much as possible. It plainly soaks into the surrounding soil; and when we consider how close to houses wells are often placed, we shall not be surprised to find that they not uncommonly drain the cesspools: thus, at Harpenden, Dr. Hunter reported in 1864 that the wells were near to the cesspools and *at a lower level*, and that the water was so execrable that it was actually abandoned by the people themselves. At Bridport, where the cesspools were often "mere excavations in the soil," and where ashes and vegetable refuse were kept in uncovered pits, the well-water became turbid after rain, and it has been known to smell offensively, "looking yellow, tasting strongly, with a nice good drainy smell!" (*Seventh Report M. O. P. C.*, p. 523.)

Escape of liquid refuse.

Wells drain cesspools.

In the reports of the Medical Officer of the Privy Council, we continually find such statements as that pumps and wells are "foul and unfit for use by infiltration from cesspools;" that the contents of wells are very foul, it being sometimes necessary to add chloride of lime to the water to destroy the offensive odour, and "yet the *dilute sewage* which they contained was largely used for drinking;" "the wells and cesspools appeared to exchange their contents with great facility." At Rugby, where the condition of the cesspools has already been described, the wells are dug in the same gravel as, and generally within 5 to 10 feet of, the cesspools. It is "physically demonstrable that the cesspools do feed the wells," and in many cases it cannot but be that "the fluid thrown into the cesspool in the morning is pumped from the well at night," yet the water is by no means generally tainted, or at least the taint appears only at intervals, or if the water be kept. This contamination sometimes takes place so quickly, from the marvellous (it would almost seem purposely intended) perfection of the communication between these two necessaries, that Dr. Buchanan states, that at Pill one of the pumps instantly furnished chlorinated water upon chloride of lime being thrown on a neighbouring muck-heap.

State of drinking-water.

This source of pollution of well-water was pointed out in 1844 by the Health of Towns Commissioners: "As houses are built and neighbourhoods become more crowded, the pollution of springs by the permeation of matter from cesspools becomes greater." "They have now got into a mode of deepening the cesspools until they come to the first stratum of sand, 6, 8, or 10 feet. This cutting generally carries the cesspool into a spring, and relieves the cesspool of the liquid portion of the refuse, which is carried away by the spring into any lower level:" a very pretty picture! And a few pages farther on we find that certain houses at Battersea "were supplied with water from springs sunk to the same level as the cesspools.

Cesspools dug down to springs.

As the springs were lowered by the consumption of the water, it was found, to the surprise of the inhabitants (!), instead of coming up clearer, it was more discoloured—by the equalisation of the water levels. . . . People have imagined that it is the gas which has polluted the water, but it is the cesspools that are now being *sunk so much lower* than formerly, partly that the water in the cesspool may not be higher than the level of the springs, and partly for the economy of cleansing." (*Mr. Joseph Quick's evidence. First Report*, vol. ii. pp. 117, 123).

We find the earth around it (the cesspool) usually saturated, and springs near are poisoned with the soakage from the cesspool; in some places it rots the floors. In taking up old foundations, the soakage "is often found to be very offensive."

At Leicester, the following state of things existed before the sanitary improvements:—

Many of the bog-hole wells in the central parts of the borough have been dug down to the water-seam, to avoid the expense of emptying—a practice which the principal well-digger of the town says he has followed for thirty years and upwards; and in support of the fact, numerous instances are given of the water being infected from the soil-pits, whose depth varies from 5 to 25 feet. (*Ninth Report, Medical Officer of Privy Council*, p. 73.)

In the Second Report of the Health of Towns Commissioners much stress is laid on this source of pollution of drinking water: "It was only fit for slopping, not for use." Another witness says: "Complaints were made of the quality of the water, which, lying close to the surface, I have no doubt was affected by the percolation of the filth from the alley;" and the excessive hardness of the well-water of towns is continually referred to, great complaints being made of the inordinate waste of soap thereby occasioned, which often induced the inhabitants to go to some distance to fetch softer water.

Hardness of polluted water.

Analysis of it.

In the First Report of the Rivers Pollution Commissioners (1868), Dr. Frankland has given some analyses of such well-water. In one case, that of the Bevington Bush Well at Liverpool, in 100,000 parts there were 86·7 of total solid impurity, containing 35·51 parts "of carbonate of lime, or their equivalent of other hardening ingredients (total hardness)," 12·61 parts of chlorine, and no less than 8·721 parts of combined nitrogen, of which 8·678 parts were in the form of nitrates and nitrites, which Dr. Frankland regards as evidence of "previous sewage contamination;" the organic nitrogen was present to a not very high amount, while of the 35·51 parts representing the total hardness, only 11·52 parts were removed by boiling, leaving 23·99 parts still in solution, so that the "permanent hardness," which is the most undesirable and the most difficult to deal with, was very high indeed.

The amount of pollution of this water may be judged of from the statement that "after its descent to the earth as rain, 100,000 lbs. of the water had been contaminated with refuse animal matter equivalent to that contained in 86,510 lbs. of average London sewage." (*First Report*, vol. i. p. 118.)

Depth of well no safeguard.

The depth of a well does not prevent its being contaminated in this way, as the above is an example of a very deep well (now closed); it does, however, afford a greater chance that the organic matters may be more completely oxidised, and comparatively harmless products formed (especially nitrates and nitrites). The general conclusion about deep well water is that "when the well is at a distance from thickly-inhabited places, the quality of the water is generally excellent, but as the population around it increases, the water gradually becomes mixed with a larger and increasing proportion of excremental soakage." (*Loc. cit.* p. 129.)

Although the mere presence of nitrates and nitrites in a drinking water cannot be looked upon as affording conclusive proof of "previous sewage contamination," it should always be regarded as a suspicious circumstance, and should lead to a search for possible sources of contamination.

Several interesting examples of the pollution of well-water by excrementitious matters are given in the Third Report of the Rivers Pollution Commissioners. Such water is described as "the bright and sparkling, but often dangerous, beverage drawn from shallow wells sunk into ground reeking with excrementitious matters" (p. 36).

Thus at Kidderminster, of a well that was pointed out "as yielding water of average quality," it is stated that "it is only 5 feet deep, and contained a liquid which was very similar in composition to that Polluted well-water. which we have obtained in our laboratory by allowing London sewage to soak slowly through 5 feet of gravel. The drinking of such water, especially in periods of epidemic disease, cannot but be fraught with great risk to health" (p. 41).

The water from a well at the Blue House School in Frome actually "contained unoxidised sewage matters, besides exhibiting a very large anterior pollution of the same kind."

Of the water of a well in Durham, described as "one of the best," it is said :—

> This water, though clear and sparkling, is shown by our analysis Often clear and sparkling. to be little else but the percolations from sewers and cesspits; 100,000 lbs. of it contain the inorganic remains of as much excrementitious matter as is present in 62,360 lbs. of London sewage, whilst the large proportion of chlorine which it contains shows that a good

Though supplied by cess-pools.

deal of urine mixes with it; indeed, the pump is in a back-yard, close to a privy and ash-pit, and the waste water from the pump-trough passes down a sewer-grid close to the pump (p. 44).

Witney derives its water supply from wells from six to fifteen feet deep.

The water of these wells is frightfully polluted, and entirely unfit for human consumption; one of them which we have analytically examined is supplied chiefly from percolations from sewers and cesspools, and contains a large proportion of unoxidised sewage matter, besides ammonia from urine (p. 45).

Well-water in towns suspicious.

It is plain from these instances that shallow well-water, however bright and sparkling it may be, is not by any means a desirable beverage, and may be a very dangerous one: and the depth of the well is merely a question of degree in most cases.

It is the old tale of the Broad Street pump over again: people prefer the cold, clear water from a well sunk, it may be, "in the foul soil of an ancient town," to the filtered water pumped them from the river (and with some reason too, for they know that the latter has been directly polluted), until a day comes when the poison of cholera or typhoid fever is introduced, and is distributed with the water perhaps to a whole district.

CHAPTER II

FILTH AND DISEASE—CAUSE AND EFFECT

It would seem scarcely necessary for us to show that the existence of the state of things which we have described in the preceding chapter is in all cases detrimental to the health of the inhabitants of the towns in which it exists, and that it must of necessity favour to an alarming extent the spread of many epidemic diseases. It will be well, however, to produce some evidence to show that such is the case, and that the opinion that the pollution of drinking-water by excreta, and of the air by emanations from cesspools and so forth, on the one hand, and on the other the amount of general sickness, and, in many cases, of special epidemics, stand in the relation of cause and effect, is a true one. With regard to the state of the city of York at the time of the plague in 1604, Dr. Laycock finds from the city archives that "there were wide stagnant moats, no drainage, narrow streets, and filthy open channels, the tide flowing above the city, and at ebb leaving sludge and mud on the deep banks of the river, and exposing the mouths of the sewers."* He reports also that the plague, in each of its visitations, broke out first in an abominably filthy place called "Hagworm's Nest," and that,

The plague at York.

* First Report, Health of Towns Commission, vol. i. p. 254.

Cholera.

curiously enough, the cholera of 1832 broke out first in the same place, and that each of these diseases progressed in much the same manner through the city, "marking the badly-drained districts by its course." From the time of the plague until the present century, it would appear, from an essay by Dr. Winteringham, that "York suffered constantly either from one epidemic or another. . . . Cholera, dysentery, or intestinal inflammation usually prevailed in July, August, and September." It is remarkable that the deaths, during the plague of 1664, were in the proportion of one death to three persons living, while from the cholera in 1832 they were in the proportion of one death to 142 persons living, a difference which probably had something to do with the improved sewerage and drainage of the city. In the reports of the Health of Towns Commissioners (1844) numerous instances are given of the production of

Typhoid fever.

fever, especially typhoid, under conditions of polluted air and drinking water. In Bethnal Green, at Punderson's Gardens, of the state of which we have already spoken, it is stated that "fever constantly breaks out in it, and extends from house to house." Of Lamb's Fields it is said (*First Report*, vol. i. p. 30): "There is always a quantity of putrefying animal and vegetable matter, the odour of which, at the present moment, is most offensive. An open filthy ditch encircles this place, which at the western extremity is from eight to ten feet wide. Into this part of the ditch the privies of all the houses of a street called North Street open. These privies are completely uncovered, and the soil from them is allowed to accumulate in the open ditch. Nothing can be conceived more disgusting than the appearance of this ditch for an extent of from three to four hundred feet; the odour of the effluvia from it is at this moment most offensive. Lamb's Fields is the fruitful source of fever to the houses which immediately surround it, and to the small streets which branch from it. Particular houses were pointed out to me from which entire families have been swept away, and from several of the streets fever is never absent." Most of the witnesses examined were of opinion that "drainage, supplies of water, and ventilation would extensively diminish existing mortality," and that where even partial improvement in these particulars, and especially more frequent removal of excreta, had been effected, considerable improvement in the health of the inhabitants had already taken place. Thus, of one court which was flagged, supplied with water, and cleaned regularly, Mr. John Liddell says (p. 110): "In the seven months ending March 1843" (before these improvements took place) "I attended forty-one new cases of sickness in that court; in the last four or five months I have had but two cases." Dr. Aldis, in describing the offensive condition of the courts and streets in Whitechapel, says that one street "is very offensive in warm weather in consequence of the exhalations from stagnant water. I am called upon to visit more cases of fever there than in any other part of the district. . . . Generally we find the most severe attacks of disease in the worst conditioned places" (pp. 112, 114). Of Liverpool, the condition of the cellars of which town we have already described, Dr. Duncan says (*loc. cit.* pp. 124, 133), "judging from the annual proportion of deaths to the population, Liverpool is the most unhealthy town in England" (that is to say, was in the years 1838, 1839, and

Fever dens.

Effect of even partial improvements.

Causes of high death-rate in Liverpool in 1840.

1840); and he contends that the causes of this are to be found in "vicious construction of the dwellings, the insufficient supply of out-offices and of receptacles for refuse and excrementitious matter, the absence of drains, the deficient sewerage, and the overcrowding of the population," and that these causes work in two ways, "partly by inducing a specific disease, and partly by deteriorating the general health of the inhabitants in such a way as to render them more prone to the attacks of nearly all diseases." In Mr. Chadwick's Report on the Sanitary Condition of the Labouring Classes in Great Britain, it is stated that in a block of dwellings for the workpeople attached to one of the factories in Glasgow, which were badly ventilated, overcrowded, and exceedingly filthy, fever was almost invariably present; "there were sometimes as many as seven cases in one day, and, in the last two months of 1831, there were fifty-seven cases in the building." After the rooms had been ventilated by tubes connected with the chimney of the factory furnace, we find "that during the ensuing eight years fever was scarcely known in the place." (*Loc. cit.* p. 135.)

Glasgow factories.

Infant mortality at St. Kilda.

A striking example of the danger arising from the emanations from decomposing excreta is to be found in the case of St. Kilda, in 1838. The diminution of the population was here shown by Mr. Maclean to be "partly owing to the prevalence of epidemics, but chiefly to the excessive mortality which is at all times going on in infancy." "Eight out of every ten children," he says, "died between the eighth and twelfth days of their existence!" and he adds that "the air of the island is good, and the water excellent," so that "there is no visible defect on the part of

Nature," and that, on the contrary, "the great, if not the only cause, is the filth amidst which they live, and the noxious effluvia which pervades their houses;" the proof of this being that the clergyman's family, with four children, although living in precisely the same manner as the people around, with the exception of the state of their houses, "are well and healthy" (p. 140). In this valuable report Dr. Duncan points out that the Ward "where the largest proportion (more than one-half) of the population reside in courts or cellars, is also the Ward in which fever is most prevalent, one in twenty-seven of the inhabitants having been annually attended by the dispensaries alone;" and he remarks that "people do not die merely because they inhabit places called courts or cellars, but because their dwellings are so constructed as to prevent proper ventilation, and because *they are surrounded with filth*, and because they are crowded together in such numbers as to poison the air which they breathe" (p. 149). In cases where middens have been placed against the walls of houses so that their fluid contents have soaked through them, and the walls been continually wet with fœtid fluid, the families are stated "never to be free from sickness." In the courts in Liverpool (p. 274) there is one ash-pit destined to hold the offal from all the houses, which, being speedily filled, allows the filthy water to ooze through the sides into the nearest cellars, and from there being no underground drainage, and no thorough ventilation, the stench is horrible. "Thousands of our poorer classes are living, or prematurely dying, in these *fever-succession houses*." In the evidence given by Mr. Kelsey on the drainage of London, when asked, "Does the state of filth and the effluvia

Cellar population most unhealthy.

Fever-succession houses.

caused by defective sewerage, by cesspools, or privies, and decomposing refuse kept in dust-bins, powerfully affect the health of the population?" says, "Yes, it does; it always occasions a state of depression that renders persons more liable to be acted upon by other poisons, even if it be not the actual cause of it. *The line of habitations badly cleansed and in this condition almost formed the line of cholera cases."* Then naming a series of localities, he adds: "All these places are distinguished by filth and want of drainage and proper washing; nine-tenths of the diseases come from these filthy places." *

Cholera.

In the reports of the medical officer of the Privy Council we find innumerable instances of high death-rate, especially from typhoid fever, being caused by the means we have above described, and being, as we shall hereafter see, very considerably lowered on the removal of these causes. In the Third Report it is shown that the water of Bedford (a town of cesspools) "was largely contaminated by decaying animal matter" (Professor Miller), and that every year there occurred there, "on an average, about thirty deaths from fever and diarrhœal diseases, to account for which number of deaths there must have been attacked every year by the same diseases, more or less severely, some hundreds of persons." In all the other towns into which the causes of epidemics of typhoid fever were inquired into, similar conditions were found. At Bathwick there was operating in a high degree the influence of fæcal putrefaction in the air and drinking-water. At Kingston Deverill the water supply was good, and the privies far removed from the houses, so that the air was not much polluted.

Pollution of water.

The cause of typhoid.

* First Report, Health of Towns Commission, vol. ii. p. 216.

Typhoid fever, on being introduced, spread so as to affect a sixth part of the population, the reason probably being "that no precautions were taken in dealing with the evacuations of the sick; that these dangerous morbid products were extensively cast on to the common dust-heaps (as doubtless also into the common privies) of groups of houses wherein fever cases had arisen." At Dronfield (in Derbyshire), where too there was an epidemic which had been prevailing for about six months, the urgent evil was "accumulation of animal filth," the diarrhœal excrement of typhoid fever cases being apparently thrown about anywhere and allowed to run down the open drains in the streets. In the Fourth and Seventh Reports the epidemics of typhoid at various places, of which we have already described the sanitary condition as regards neglected privies, midden heaps, cesspools, and so forth, are shown to have always taken place in connection with accumulations of decomposing filth. Thus at Steyning, a town naturally very favourably situated, there have been continual "epidemics of cholera, small-pox, scarlatina, and diphtheria;" and with regard to typhoid fever it is stated that the cottage in which it was most fatal "was that in which fæcal impurity had been the greatest." (We have already described the condition of this cottage.) In the colliery settlements of Gilesgate Moor, which were in a most offensive condition, and where the inhabitants actually wantonly destroyed some privies which were provided for them, it is stated "that disease was very common, and that minor ailments, nausea, vomiting, and diarrhœa are very constantly present." In one house in Seacroft there were five cases of typhoid and one of small-pox

Typhoid excreta.

Most disease where most filth.

at the same time. Dr. Stevens reported that there was no drainage there, and that the wells were close to filthy pigsties and midden heaps. The water was foul. With regard to the sanitary state of Bridport, a town which "enjoys, by its position, elevation, and soil, every natural sanitary advantage," Dr. Buchanan reports that the death-rate from fevers "in persons of all ages has been 114," and that in one of the parishes it has been actually 136. Of this town he says: "Scarcely one London district really reaches the fever death-rate of Bridport, for those which appear to exceed it are chiefly those in which the great metropolitan hospitals receiving fever are situated. With London City, with Clerkenwell, with Marylebone, and St. Pancras, Bridport will not bear a moment's comparison as to its fever mortality; no, nor even with Holborn, or Bethnal Green, or St. Giles's."* (We have already described the condition of the cesspools and ash-pits of this town.) At Ashby-de-la-Zouch, after an absence of typhoid fever for two or three years (since the sanitary improvements), it reappeared, owing to the filtration into a spring from an adjoining cesspool. It was shown that persons inhabiting more filthy houses than the one in which the fever appeared, and close by, but who got water from a neighbouring tap, were never attacked.

Fever death-rate of Bridport.

Spread of cholera.

At Pill, near Bristol, the cholera having been introduced into a public-house in a low-lying part of the town, at once spread with fearful rapidity, especially along the filthy creek which has been already described as an open sewer. At Carnarvon, too, the great spread of cholera was traced to the especially bad hygienic conditions. The researches of Dr. Snow and John

* Seventh Report, Med. Off. Privy Council, Appendix, p. 524.

Marshall, Esq., F.R.S., have proved that cholera is spread by contaminated drinking-water. At Terling and many other places typhoid fever has been traced to the contamination of the wells from the foul cesspools. In fact, all the evidence that we can collect leads us to the conclusion that "there cannot be a healthy population living over or amidst the emanations from cesspools." But this conclusion was come to long ago. We find from Dr. Laycock's evidence, before quoted (see page 19), that Caius (or Kaye), in his "Boke, or Counseill against the Disease commonly called the Sweate or Sweatyng Sicknesse," gives the following wholesome advice :—"Take away the causes we maye, in damnying diches, auoidynge cariôs, lettyng in open aire, shunning suche euil mistes as before spake of, not openynge or sturrynge euil brethynge places, landynge muddy and rottē groundes, burieng dede bodyes, kepyng canelles cleane, sinkes and easyng places sweat, remouynge dongehilles, boxe and euil sauouryng thynges, enhabitynge high and open places, close towarde the sowthe, shutte toward the winde, as reason will and the experience of M. Varro in the pestilēce at Corcyra confirmethe."

Kaye's advice.

It is continually pointed out that sickness is the chief cause of the non-payment of rent. One witness says: "Three out of five of the losses of rent that I now have are losses from the sickness of the tenants, who are working men. . . . Rent is the best got from healthy houses." Another says: "Sickness at all times forms an excuse for the poorer part not paying their rent, and a reasonable excuse." (*First Report H. of T. C.*, vol. ii. pp. 303, 312.)

Sickness causes non-payment of rent.

So that filth causes sickness, sickness inability to work, inability to work poverty and non-payment of rent, to say nothing of starvation.

Legislative interference.

With regard to the interference of the Legislature to prevent a man doing as he likes in his own house, we may quote again the remarks made by Mr. Home on the former state of Liverpool:—"The man who, in a crowded street, is living in filth and breathing a putrid atmosphere, or who makes that street a receptacle for the offal which he casts from his dwelling, becomes the instrument of danger to his neighbour by spreading infection, and he not only hazards his own life, but endangers that of others. The man who erects a flimsy edifice in a crowded thoroughfare, which by its falling may destroy life, should be prevented doing so, and he who constructs a house to let for profit and pays no attention to those matters which are essential to comfort, but, on the contrary, so constructs it as to engender fever and endanger the lives of his tenants—all these are cases where, with propriety and in justice, the Legislature ought to interfere and to insist upon such a mode of construction as will not endanger human life."*

A man's right to injure himself or his own property, but not the community at large, nor public property.

In vol. i. of the Brussels Public Hygiene Reports the conditions for the interference or non-interference of the Legislature are stated very exactly:—"Whenever an abuse in the exercise of the right of proprietor can only injure him who commits the abuse, the public authority is incompetent to interfere, and in this case a citizen has the right to use and abuse his own person and effects. Whenever, on the contrary, the possible consequence of this abuse may be to cause the breaking out of epidemics or public calamities, the authority can, and even ought to interfere

* First Report, Health of Towns Commission 1844, vol. i. p. 282.

by prescribing regulations which forbid this abuse." As a forcible illustration the following is given:— "Because each farmer has the right to poison his own cattle, if he is such an enemy to his own interests as to commit this mad act, it does not follow that he has a right to sow a field with poisonous plants, the emanations from which might injure the health of the cattle of the neighbourhood;" and the conclusion is, that "each administration can order, and even ought, in the performance of its duty, to order, in the construction of habitations, everything which is essentially necessary to ward off epidemics, and to guarantee to the neighbours a healthy state of the atmosphere." (*Rapports du Conseil Supérieur d'Hygiène Publique*, 1^er^ *vol.* pp. 5, 6: Bruxelles, 1856.)

Example.

Duty of the public authority.

CHAPTER III

IMPROVED MIDDEN-PITS AND CESSPOOLS—MIDDEN CLOSETS, PAIL CLOSETS, ETC.

THE simplest form of midden heap as it exists in all uncivilised places having been already described, it remains for us to allude to several improved forms of middens which have been fully described in a Report by Dr. Buchanan and Mr. J. N. Radcliffe, of which Dr. Buchanan courteously lent us the proof-sheets.*

Improved midden-pits, lined with cement.

The first improvement on the old midden-pits is to make them impervious by lining them with cement, and rounding off the angles so as to make them concave at the bottom. Thus at Nottingham this is done, and the ashes are thrown in by a door at the side: here the pits are not drained, but are roofed over. The closets are not allowed to be less than 4 feet 6 inches long by 3 feet broad and 7 feet 6 inches high; their roof must be louvered for ventilation, and their floor sloping, that it may be easily washed. The single midden-pit contains 80 cubic feet up to the level of the ash-door sill, and one lengthened pit may be continued under a row of closets on the "block system," as it is called; it must be at least 15 feet from the house. A single closet costs from

* This Report has since been published in the Appendix to the Twelfth Report of the Medical Officer of the Privy Council.

£9 to £10, and several in blocks from £5 : 10s. to £6 : 10s. each. The closets are limewashed twice, and the pits emptied regularly four times a year. Dr. Buchanan found them clean, not wet, and productive of no great nuisance; but there was a smell, especially in the larger ones, when the ash-pit door was opened. Slops must not be thrown into these pits, or they invariably become offensive. At Stamford, the corporation have approved of a somewhat similar plan to the above, with the improvement of a shallower pit and a hinged seat, so that the ashes can be thrown directly on to the excrement: one of the doors into the midden is to be made large for the convenience of the scavengers. A "block" of four such privies will cost £35 : 9s.; of only two, £22. Shallow pit: hinged seat.

In Manchester, as is well known, ash-pit middens are very much used. In his evidence given before the Royal Sanitary Commissioners in 1869, Sir Joseph Heron, the town clerk of Manchester, said: "The arrangement which we try to carry out is to deodorise to the extent practicable, by means of the ashes which necessarily are met with in every dwelling, and by an improved construction of ash-pits. There is a grid, as they call it, to allow the small ashes to pass into the ash-pit, and in that way also to have them cast on the fæcal matter; and it is generally said, and I certainly have been in privies and ash-pits which have been constructed upon a good principle, where there has not been anything like the smell which, I am sorry to say, I certainly often experience in water-closets in hotels in London." He, however, acknowledges that the plan is adopted merely "with a view to improving and getting rid as far as possible of the objections which may perhaps be necessarily incidental Manchester plan.

more or less to that system," and that its object is to "keep out of the sewers as much as possible the fæcal matter which in itself renders them polluted," "until a mode of disposing of and dealing with sewage has been in some way satisfactorily determined."

Conditions required.

The specifications for the Manchester midden-pits require (1) that the pit "shall receive no moisture from the soil around, nor allow of any soaking of liquid filth out of it:" and this end is as far as possible secured by lining the pits with Rochdale flags embedded in mortar, and by giving the floor an inclination of not less than 3 inches to the outlet in connection with the drain; (2) "dryness, as far as practicable, of its contents:" this being secured by the inclined floor, and by (3) "exact and efficient covering up of the deposited excrement by the ashes and house refuse;" an end attained by one of several methods:—(*a*) a grid, as described by Sir J. Heron, into which the ashes are thrown, and which sifts them, sending the fine ash by means of a shoot on to the excrement, and retaining the cinders to be used again as fuel; (*b*) a hinged privy seat, which can be lifted so that the ashes may be thrown on to the excrement: with this plan is sometimes combined a special urine catch-pan, so that the contents of the midden have a greater chance of being dry; or (*c*) the front board of the privy does not quite reach to the floor, and carries a narrow step, between which and the floor is the space through which the ashes are thrown: the seat is hinged at the back, so that seat, front-board, step, and all can be lifted up when the pit has to be emptied; and (4) "the dispersion, at some safe point, of any noxious gases evolved from the contents of the midden," which condition is secured by the construc-

Ashes, how used.

tion of ventilating flues of not less than 81 square inches in area, which are carried up outside the wall of the house to 3 feet above the eaves. These middens (except of form *c*) are emptied through holes closed by ledged doors which lead into the passage running behind the row of houses, and the privies are covered with well-pointed slated or flagged roofs. Ventilation.

These requisitions remind one of the regulations for the French *fosses permanentes,* except as regards the question of *dryness* of the contents, in which respect the midden-pits present a great advance on the foreign system. Their chief fault, as middens, is that they are too large, and so the accumulation becomes very great in them; they should also not be allowed to be close to houses, as one cannot be very sure that liquid does not, occasionally at any rate, escape from them.

At Salford, where midden-pits are almost universal, they are required to be 3 feet from the wall of the house, to have a drain into the sewer, and to be free from leakage; the closets must be outside the house, and have near the top an opening to the air of 12 square inches at least, and there must be one to every house. The slab is constructed so that the ashes are thrown under the "upright," as in the third Manchester plan: "Except where a closet was locked, and its use restricted to a single family, or at the most to two or three families, we found them in a most unsatisfactory state," the fact being that the people threw the ashes on the open ash-pits close by rather than under their own privy seats; thus showing that the lower classes of people cannot be allowed to have anything whatever to do with their own sanitary arrangements: everything must be managed for them. People don't use them properly.

A somewhat similar plan obtains at Saltaire, a village near Bradford, and although the slops go into the sewers, the midden-pits are offensive unless the ashes be very carefully thrown on to the excrement, a precaution which people, as a rule, cannot be expected to take; when well used, however, they give no offence.

The best form of midden-closet is the one in use at Hull: it was tried because "the water-closet, *used in common by several families*," was, as might be expected, "everlastingly a nuisance." (The italics are ours.)

Smallest and best midden-pit.

In this plan there is no pit at all, but the *space underneath the seat*, between it and the floor, is the sole receptacle of the soil and ashes, which latter are thrown in with a scoop through the hole in the seat. The front board is movable, so that the scavenger may get at the contents with a spade. When these closets are used by decent people they are clean, and the contents dry and inoffensive, as plenty of ashes are thrown in, and the slops go into the drains; but when used by several families they were found to be overflowing from not having been emptied often enough; they then require to be emptied every day. "Many of the privies in poor quarters can only be reached through the house."

Scavenging.

The scavenging system is good. The town is divided into forty-six districts, of from 300 to 700 houses each. These districts are let out to separate contractors, one contractor being allowed to take two districts if he chooses, but not more. These contractors are paid by the value of the manure, and by an allowance which the Board makes them of 1s. to 1s. 6d. a year for each house, so that the proceeding costs the Board £2000 a year, and is likely to cost them more, because the mixed soil and ashes do not sell well, and because increased supervision is necessary.

Where, then, the midden system is continued, the closet should be *away from the house,* and should be roofed in, floored with sloping flags, and well ventilated; the midden-pit should be very small, preferably only the space under the seat between it and the floor; it should be impervious on all sides, and should not on any account be against the wall of the house, or even near to it; it should not be drained, for if the ashes do not keep the contents dry, or nearly so, the system is a failure. Best conditions.

There can be no doubt, however, about the fact that any form of this plan is unadvisable, from the great expense of scavenging, and the inconvenience caused by the frequent visitations of the scavengers or "nightmen," especially as they have to dig out the contents of the pits. People do not like these frequent visitations, and this objection will be found to apply to many other systems which are now on their trial. Any plan which will make such visits as *infrequent* and as *short* as possible will be preferred by ninety-nine persons out of a hundred. Objections.

IMPROVED CESSPOOLS.

To obviate the evils of soakage, etc., "we line the cesspool with cement, and provide an overflow drain from it into the common sewer or the nearest outlet;" in other words, the improved cesspool is a sort of *cul-de-sac* from the house drain, which catches the more solid matters, and keeps them for an inde- Cesspool lined with cement, and drained.

finite time underneath the house or in close proximity to it, allowing the more liquid part to run away into the nearest sewer; the advantage of the plan being, it is presumed, the value of the manure so preserved. As to the relative value of what is lost in this way to what is kept, we must refer the reader to the head of "Utilisation." It must not be supposed that this care to prevent pollution of the neighbouring wells was always taken, for generally the surface drains were left to "carry off the sulliage from *overflowing cesspools*," as at Ely and Chelmsford; and where the pits are drained, as at Stratford-on-Avon, they are often a nuisance through the choking of the drains; the actual disadvantage in some respects of draining them is seen from the fact that here they are only "*supposed* to be emptied about *once a year*." If a nuisance, and *if complained of*, the inspector removes them. No wonder that improvement is so slow! (*Ninth Report M. O. P. C.*, pp. 155, 179).

Overflow when not drained.

At Worthing the cesspools were "constructed so as to retain liquid as well as solid contents" (of course as far as practicable); "the overflow of them commonly passing into the trough system of public drains; and instance after instance is given of cesspools *requiring to be baled out*, or overflowing through inefficiency of drains from them." (*Loc. cit.* p. 194.)

At Liverpool, the Health Committee, in 1846, ordered all cesspools, middens, and water-closets to be drained into the sewers. "The perfect drainage of middens and cesspools was a great sanitary improvement. It lessened materially, though it did not entirely remove, the evils of the existing system." (*Report by Dr Trench, First Report R. P. C.*, 1868, vol. ii. p. 303.)

But it must be observed that the whole principle of cesspools is given up by draining them into the sewers, and it becomes difficult to see the object of their existence at all, especially as it is probable that, in the words of the last-mentioned authority, they "do, by their drainage, pollute the sewers to an equal, if not to a greater, extent than water-closets." (*Loc. cit.*)

Principle of cesspools given up, if drains are provided.

The closets, or rather privies, are of course of the simplest construction, as a general rule, and require no special description.

Where the cesspool system has been strictly adhered to, as in many continental towns, the huge pits, which are generally placed under the court-yards of the houses, are lined with cement, so as to be as impervious as possible; and in Paris and some other towns they must be provided with a ventilating shaft reaching up some feet above the roofs of the houses. The general rule is, that they shall be so large that they only require to be emptied once in three or four months: and this is usually done by pumping the contents through hose into large cask-shaped carts (*tonneaux*), which are sent for the purpose at night when required; or by air-tight carts, in which a partial vacuum is first created, so that the sewage is forced up into them through the hose by the pressure of the air, and pumping is not required.

Paris, etc., "fosses permanentes."

Thus, at Brussels, the specifications for the *fosses permanentes* require that "the pits (*fosses*) should be constructed according to the rules of the craft, with a *concave* floor (*pavement*) and rounded corners, and covered with a layer of cement or *trass*, which does not leave any interstice by which the liquids and the (fæcal) matters could infiltrate themselves into the masonry and into the surrounding soil. When

Brussels.

(fæcal) matters are allowed to remain in the pits, these must be provided with a ventilating pipe directed aloft, so as to carry away the emanations far from inhabited places." And with regard to the emptying of these pits, it "ought to be conducted with the greatest care. All precautions should be employed which may be necessary in order that the removal of the (fæcal) matters shall not infect inhabited places; to this end, recourse must be had as much as possible to pumps, which remove from this proceeding its inconveniences and its dangers." (*Conseil supérieur d'Hygiène Publique: Rapports adressés à M. le Ministre de l'Intérieur*, 2e vol. pp. 242, 243. Bruxelles, 1860.)

Precautions.

Despite all such precautions, the *fosses permanentes* are not water-proof, but allow percolation into the surrounding soil to a great extent; and the operation of emptying them is *necessarily* a most offensive one, as every one knows who has passed along streets while it was going on, although (at any rate in Paris and Lyons) a sufficient amount of disinfectant fluid is supposed to be thrown down one of the pipes into the cesspool before the pumping commences.

Emptying.

At Paris these cesspools are often provided with a separator to keep the solids and liquids apart: this is simply done by having two or more reservoirs, communicating one with another by means of small holes through which the liquid parts pass; each of these chambers is provided with a ventilating chimney. This separation materially retards decomposition. The Council of Salubrity found, "with a separator and good ventilation, absence of odour, and completely healthy conditions (*assainissement*); when ventilation is not provided for, or is badly understood, the sepa-

"Séparateurs."

rator only gives what result it can, and does not prevent the production of a bad odour." (*Tardieu, Dictionnaire d'Hygiène Publique,* art. "Fosses d'Aisances.")

The object of the precautions taken with regard to the pits and closets is to ensure as far as possible—

"(1) Absence of noxious or disagreeable miasms and odours. Conditions required.

"(2) Solidity, simplicity, and economy of the apparatus.

"(3) Preservation of the contents in their natural condition, and their removal as promptly as possible by methods calculated to obviate all inconvenience and all danger."

With regard to the closets for public buildings (hospitals, schools, prisons, barracks, etc.), it is ordered that "the soil-pan must be in porcelain (*faïence*), or in solid glazed stoneware. It is provided with a groove, to be filled with water or wet sand. The lid, to close it hermetically, must to this end be fitted with a ridge which enters the groove so as to prevent the issue of gases. This method has been applied with success in the cells of prisons recently constructed, where there is in each cell a completely inodorous privy-seat (*siége d'aisances*).

"The pipe connecting the seat with the cesspool must communicate as directly as possible with the cesspool; its internal surface must be quite smooth, and it must be made of a material which will not be corroded by the action of the liquids or gases which may be in contact with it: to this end it must be of lead, or preferably, in large establishments, of stoneware glazed on the inside; the various pieces of it must be firmly fixed with well-closed and luted joints. "Tuyau de chute."

Trapped. This pipe should have an apparatus for intercepting the air (valve or siphon), which may be washed by throwing water down or allowing some to run through it. There should be two such valves or siphons, the one directly under the soil-pan, the other at the lower extremity of the pipe: this lower siphon is not to plunge into the contents of the cesspool or sewer, its contents must *pour themselves* into that receptacle.

"At Brussels it is customary to place at the foot of the descent-pipe an iron reservoir which fulfils the part of a siphon. This apparatus allows of the cesspool being placed at a convenient distance, a communicating sewer being made. When the closets are indoors it is advantageous to arrange a sufficient and well-aërated space between the rooms of the house and the closet,* and to establish in this latter, besides the window or opening which lights it, a ventilation-pipe.

Ventilation of closets.

"Each closet is to have only one window, and the doors must be arranged so that the lower part of the legs and the upper part of the body can be seen." (For references see p. 45.)

Closets abroad.

At this point a few words must be said on the ordinary closet arrangements of continental towns as a general rule. We have observed closets of three kinds: (*a*) those in which the seat is made of wood, and which answer their purpose tolerably well in private houses, but which invariably become excessively filthy in all public places from the prevalent abominable custom of standing upon the seat; (*b*) those which have a stone seat, if a construction can be so called which could never have been intended for any one to sit upon: these are infinitely preferable to the

Seats.

* This M. Tardieu terms a "surcroît de précautions!"

former ones, wherever the above-mentioned habit is usual, as the stone slabs do not become sodden like wooden planks do, and can be washed more easily and more effectually; and (*c*) those without any pretence at a seat at all, and in which the convenience (?) consists of a zinc floor inclining to a hole, immediately beneath which is sometimes a swinging trap which closes the mouth of the pipe or drain, but which gives way with a slight weight, returning into position immediately afterwards. Of the three forms the last is undoubtedly the best fitted for all public places in countries where seats in closets are obviously an unnecessary luxury, and soon become an unmitigated nuisance. No seat.

In all these cases the pipe descends directly from the soil-pan, when there is one, from the floor when there is not, to the cesspool under the house, and the flushing, such as it is, takes place when the slops are thrown down. There is often no sort of trap at either extremity of the pipe, so that the putrid gases formed in the cesspool rise up into the rooms of the house; when, however, one of the above-mentioned simple traps, invented by MM. Rogier and Mothes, is placed at either end, or one of these at the one end and a siphon at the other, there is much less danger of this. Often no trap.

The ventilators of the cesspools are generally carried up along a stack of chimneys, so that the air in them is warmed and an upward current created. Although they rise above the chimneys, there must be a risk of the foul air being occasionally blown down the chimneys into the houses. Ventilators.

Several methods for emptying cesspools by pneumatic pressure into vans or "tonneaux," from which the air has been previously exhausted, have been for Emptying cesspools by pneumatic pressure.

some time in use in many continental cities. The latest of these is that known as *Talard's* system, which has been adopted in parts of Paris, Rheims and Metz, and a similar process is now in force in Strasbourg and Carlsruhe.

Talard's system.

In Talard's system the contents of a cesspool can be extracted at the rate of about 20 cubic yards per hour. A steam vacuum pump is attached to a small portable locomotive engine, to exhaust the air from the receiver. The receivers are barrel-shaped, of a capacity of about 3½ cubic yards, and are made of light steel plates. Each receiver is mounted on framework on four wheels, and can be easily drawn from place to place by a pair of horses. It is fitted with a glass gauge at one side, to show how full it is, and has a large full-way valve at the lower end, to which the flexible tube is attached.

Mechanical joint for lengths of hose.

On the cesspool being opened a strong, flexible 5-inch tube is plunged to the bottom of the contents, the other end of this tube being connected with the valve of the receiver, which has already been connected with the engine by a smaller tube from its upper part. The special feature of this system consists in the invention of a mechanical joint to connect the lengths of hose; the joint is both water-tight and air-tight, and can be made in two or three seconds by an ordinary labourer, and as easily disconnected. The engine being started, the noxious gases are first extracted from the cesspool, passed through the furnace and burned; the air is then exhausted from the receiver, and on the valve being opened the contents of the cesspool rush up, filling the vacuum in about three or four minutes. The valve is then closed, the pipes disconnected, and the receiver taken away to be replaced by others, until the cesspool is entirely empty. The receivers can either be discharged into close barges, specially constructed for the purpose, in which case the pipe is connected at one end to the receiver and at the other to the barge, so that the contents are transferred from one receptacle to the other by gravitation, without being exposed to the air; or they can be emptied on to the land in the usual manner for fertilising purposes.

We have no knowledge as to the practical working of this system on a large scale, but we know what air-tight carts filled by "pneumatic pressure" are in continental towns, and have no desire to see their disgusting nocturnal processions in London or anywhere else. Every possible precaution was taken in Paris to secure as far as possible freedom from offence, and yet when the "tonneaux" were filled, and miles from the place where they got their load, they spread around them, as they went along towards La Villette, a most abominable stench. Remarks.

As to the expense of a cesspool, it may be stated that such a one as is put to a labourer's house costs, for digging and lining with brick, from £1 : 10s. to £2, and that if lined with cement, without which there is no pretence at imperviousness, it would cost £1 more. If an overflow drain were provided, it would cost 1s. 6d. per foot, and be not less than 30 feet long (probably 50 feet); this, with the cement for a cesspool 3 feet 6 inches in diameter, "would not at the London prices be less than £3 : 5s." "Making the whole expense of the cesspool so protected about £5, and involving an annual rent, at 10 per cent, of 10s. for the cesspool alone." (*First Report H. of T. C.*, vol. ii. p. 318.) Cost of a cesspool.

In Paris. The expense in Paris of making a cesspool varies from 160 to 200 francs (£6 : 8s. to £8) for one of 8 cubic metres (282·4 cubic feet), provided with separators, ventilating shafts, etc.; such a reservoir "only becomes full at the end of a year in ordinary houses, that is to say houses inhabited by thirty persons."

Expense of cleansing. The Health of Towns Reports inform us that the average expense of cleaning a cesspool in the metropolis was about £1 per annum. When this is tested by examining the evidence, it is found that in Southwark and Battersea the expense was "£1 *each time* for small tenements, and as much as £3 for large ones." Where percolation into the surrounding soil is favoured, the cost is of course lessened. "From four to eight-roomed houses do absolutely cost about 3d. per week for cleansing the cesspools" (*loc. cit.* p. 122). So that it is to the advantage of the owner of a cesspool in a large town to adopt the Northampton principle as much as possible, and assist the escape of liquid sewage into the surrounding soil, and therefore, as we have already seen, into the neighbours' wells, as much as he can. Surely it would be difficult to say anything more condemnatory of a system than this. No one maintains that it is an improvement to well-water to be "diluted sewage;" whether it is a sanitary advantage or not, will be considered in another place. The total cost then, including the interest on the original outlay, would be "in the metropolis" from £1 to £1 : 10s. per annum; or £1 : 2s. per annum, or from 4d. to 5d. per week, for common tenements; and this does not include the cost of the closet itself.

TEMPORARY CESSPOOLS—"FOSSES MOBILES," PAILS, BOXES, TUBS, ETC.

It is plain that in order to lessen as much as possible the chances of soakage from cesspools, just as from middens into which ashes, etc. are put, the best thing to do is to diminish their size as much as possible, so that they may be emptied frequently; this presenting an additional advantage in the more rapid removal of the refuse matters from the proximity of dwellings. Diminution of size.

The most obvious example of this plan is to be found in the continental *fosses mobiles.* We extract from the Belgian report before quoted (page 38) the following account of the system as practised at Brussels, especially in large public establishments:— "Fosses mobiles."

"The system of closets with *fosses mobiles* has for its object the collection of (excremental) matters in a state of purity, without mixture with water, in desirable conditions of cleanliness and absence of odour."

"(1) *Seat.*—This consists simply of a soil-pan of stoneware or *faïence.*" There is no woodwork, and the soil-pan merely projects from the top of the descent-pipe. "Its border has a groove in it filled with water or sand, into which the raised rim of the lid fits. "Siége."

"(2) *Connecting-pipe.*—This pipe, straight, *without siphon,* joins the descent-pipe at a very acute angle (22°), and is about 4 inches in diameter inside; it is, like the next, made of stoneware, glazed inside. "Tuyau manchon."

"(3) *Descent-pipe.**—This is from 6 to 8 inches in internal diameter; it is straight, vertical, and is com- "Tuyau de chute."

* Soil-pipe.

posed of a series of pipes connected with each other by dry sand joints, without cement, fixed to the wall by iron bands; it rests, at the ground-floor level, on a strong flagstone. Its prolongation, through and below this stone, consists of a sliding pipe of wrought copper, capable of being lengthened or shortened, and solidly fixed to the stone by a cast-iron connecter. A sort of circular shallow dish (*écuelle*), which can be hung under this last part of the descent-pipe, serves at a given moment to shut its lower orifice.

"Tonneau," or "Tinnette."

"(4) *Tub* (*tonneau*).—The excremental matters coming down the descent-pipe fall into a tub of from 2 to 3 hectolitres (44 to 66 gallons), into which dips, fitting tightly (into a hole in the top), the lower part of the pipe. A cover fitted with a spring serves to shut and lute, by means of a little hemp, the tub when it is full. Placed on a stand furnished with wheels, the tub is easily managed; when filled, it is immediately replaced by another similar contrivance. If the tub is underground, the rails (on which the stand moves) should be placed on an incline, so that the removal and replacement may be easily effected. The underground chamber must be isolated, and the entrance to it placed outside the building. The thorough tarring of the interior of the tub not only preserves the staves, but also partly neutralises the effect of the mephitic gases which the (excremental) matters disengage.

"Tuyau d'évent."

"(5) *Ventilation-pipe.*—To prevent the smells and gases which are given off from the mouth of the tub from spreading themselves (in the house) by means of the opening in the privy-seat, at the upper extremity of the descent-pipe is fixed a ventilation-pipe, which rises above the coping of the roof, and the action of which is increased by means of a vane, or any other contrivance producing the same effect."

The expenses of this apparatus are said to be "relatively small, and are besides amply compensated by the returns from the sale of the manure."

Earthenware urinals are placed in the boys' and men's departments, and are connected with the soil-pan or one of the descending pipes by means of a leaden pipe slightly bent in the form of a siphon.

"Siéges d'aisances mobiles."

With regard to the *fosses mobiles* for the sleeping-rooms and sick wards the following directions are given :—"These seats must be arranged so as to cause no smell. Wood is to be forbidden, as it is readily impregnated with fæces and urine; *faïence* stoneware, or pottery, as being too heavy and liable to be broken. Preference should be given to the utensil of galvanised iron or of non-oxidisable iron, used in prisons: closed by a lid of the same metal, which fits into a groove filled with water, this vessel is carried with one hand, by means of a handle fastened to two rings on it, without allowing gas to escape during its passage. It can be placed in an ordinary bed-chair when thought necessary."

Fault of ventilation.

In this system as applied to houses it will be seen that there is no trap, no siphon, nor indeed any contrivance to prevent the gases which accumulate from rising into the connecting-pipe and soil-pan ; reliance is placed on the vane at the top of the descent-pipe," which, it is presumed, if well arranged, causes a draught upwards, and upon the supposed air-tight lid. It is easy to see, however, that the draught can never be sufficient to draw the air very forcibly downwards when the lid is lifted, and so the light gases collected in the soil-pan (which is most conveniently placed to receive them) take this opportunity of escaping into the house. If by any chance the ventilation arrangements do not act as they should, there is nothing whatever to prevent the house being supplied with air through the privy-seat as soon as the lid is lifted.

Various devices are employed in Paris for the separation of the liquid from the solid contents in these tubs, and sometimes the liquid parts run away from them directly to the sewers, or into a cesspool.

Cost. The price of a single *fosse mobile* with a *séparateur* is from £2 to £2 : 10s.; for one having three divisions, and so serving for several descent-pipes, from £6 : 10s. to £7. The expense of emptying the solid matters alone for a house of 30 persons, and furnished with a *séparateur mobile*, is: Removal of twelve boxes at 1 fr. 50 c. a year, 18 fr.; hire of apparatus, 20 fr.; *i.e.* 38 fr., or about £1 : 10s. a year altogether. This, M. Tardieu remarks, is without doubt a high price; "an inconvenience which is inevitably attached to the system of *fosses mobiles*, but which is compensated for by the easy and prompt removal of the putrescible matters." (*Dictionnaire d'Hygiène Publique*, art. "Fosses d'Aisances.")

Authoritative supervision. The establishment and management of these contrivances in Paris is strictly under the control of the authorities; they may not be fixed, moved, or emptied except by duly authorised persons, and since 1851 they must be supplied with a separating apparatus.

Chesshire's Intercepting Tank is a variety of the *fosse mobile;* its object is, then, to separate the solid excreta from the urine, which is allowed to run away into the sewers.

The plan or form at present preferred is that of an iron box, large enough to hold the solid part of the excreta of an average household for from eight to twelve months, and yet, when full, within the power of two strong men to lift. This box is 2 feet 4 inches long by 18 inches wide and 18 inches deep. The pipe from the privy or closet passes into the top of the box, by preference at the opposite corner to the outlet or waste-pipe, which, placed at the bottom of the box, is divided from the main part by a perforated grating, extending across the corner and the whole height of the box. Except as to the inlet and outlet pipes, the box is hermetically sealed, though the lid can be readily removed when it is desirable to empty it. The connection of the inlet and outlet pipes to the box can also readily be separated and remade without the assistance of a plumber. Description of tank, etc.

A full box can be removed, and an empty one put in its place, in five or ten minutes, and this, if necessary, may be done in the daytime, without any annoyance to the household, neighbours, or passers-by. The removed box, full as it is of most valuable manure—in fact, a human guano—may now be carted away, and its contents reduced, by a liberal admixture of fresh loam or water, to a strength suitable to the crop or soil to be fed with it. (*Prospectus of Patentee.*)

Surgeon T. G. Hewlett, Health Officer and Coroner to the City of Bombay, writes as follows of one which he substituted for a water-closet and cesspool :—

An earth closet was inadmissible within the house, so I placed within the cesspool one of Chesshire's intercepting tanks. That is almost hermetically sealed, as it is double syphon-trapped. The solid matter, paper, etc. is arrested by a screen which permits the passage of water, which flows away through a syphon-trapped glazed pipe, and eventually discharges itself at a distance from the house, beyond the property, into a surface drain. The smell, both inside and outside the house, before much complained of, has entirely disappeared. The iron tank will require cleaning periodically—the patentee states, once in six months ; but this is a matter for experience to decide. (*Report of a Sanitary Tour, by Dr. T. G. Hewlett,* in the *Appendix to the Report on Measures adopted for Sanitary Improvements in India, from June* 1869 *to June* 1870, p. 233.) Good results.

It will be seen from the above quotation that Dr. Hewlett considers this intercepting tank superior to the earth closet for the interior of houses; he, however, only regards it as a substitute for the cesspool, for after examining it at Birmingham he writes —

Better than cesspool.

This appears to be a better form of cesspool, and may be worth trying in places that have no regular system of drainage. (*Loc. cit.* p. 242.)

The German system of movable receptacles (*Abfuhrtonnen*) is much the same as the French, but the simpler form of a mere bucket under the privy-seat is in use in many towns (Berlin, Leipsic, etc.)

Vanishing point of cesspool.

This is the vanishing point of the undrained cesspool. We have seen it reduced to a 20, 40, or 60-gallon cask in the larger *fosses mobiles;* now we find it reduced to a mere box, pail, or bucket, just as we saw the midden reduced to a mere space under the seat, between it and the flagged floor; in each case the underground pit is entirely abolished.

From Dr. Buchanan and Mr. Radcliffe's report we find that this system is in practice at Leeds and at Nottingham; at which latter place, however, a little earth or ash is put into the bottom of the box, to prevent the contents from adhering to it. There are, besides, separate bins for the ashes and house refuse. These boxes are removed daily, or two or three times a week, being either emptied into the carts or carried off altogether and replaced by fresh ones; the scavenging is all done in the night, and the refuse is taken away from the town by canal barges and sold for manure.

Movable tubs.

At Rochdale, too, movable tubs under the privy-seat are in vogue. A little fine ash and common salt is sprinkled over the bottom of the tub for the same purpose as at Nottingham, and also perhaps with the view of retarding decomposition; the ashes and house refuse are thrown into a separate tub; the pails are made from disused paraffin casks, each cask being cut in two; they are fitted with iron handles and with tightly fitting lids, and cost 3s. 4d. each; they are changed twice or three times a week, and cause very little nuisance either in the houses or in the streets.

The cost of changing a midden closet into a pail closet is 30s., or £10 for seven.

Pails in Edinburgh.

At Edinburgh the system of simply placing pails full of excrement, urine, and general refuse outside the houses for the scavenger to take away, has been long practised, as there has been literally no accommodation of any sort in the large tenements. The pail closet system has now been established there on a regular footing. The closets, which are roofed in, are placed in two rows, with a passage for the scavenger between them; the seats and divisions between the recesses are made of smooth slate; under the aperture is a short earthenware funnel, and below it is placed a movable metal pail; this is removed daily by the scavenger and the privy cleansed, a reservoir of water being provided for this purpose. At Glasgow too the same system is at work "in various public and semi-public closets."

Conditions necessary.

The pails or boxes should be round and straight; square ones are not so strong nor so easily cleaned; they may be of wood, well pitched inside, or of galvanised iron. The closets should be made of impervious materials as much as possible, as then they are less liable to get fouled, and are also more easily washed; the ash-tub should be under a roof of some sort, or its contents will get wet and become a nuisance. The pails should be changed daily.

Difficulty from number of pails.

Dr. Trench, then medical officer of health for Liverpool, has made some practical observations on the difficulties of applying this system to large towns.

He has calculated that the space that would be required for the spare receptacles for the borough of Liverpool, allowing that they were packed as close as possible, would be 11 acres, 2 roods, and 32½ perches; and that if they "were put on a railway, four abreast, they would extend to Ormskirk, a distance of 12 miles." He adds: "I can form no guess as to what would be the extent of land required for the reception, emptying, washing, and deodorising of the receptacles directly on removal from the various houses; nor can I conceive where, within the area of our overcrowded borough, such spaces could be found; nor where, outside and beyond the precincts of the town, the Health Board of any suburban locality would allow their parishioners to be poisoned for the convenience of Liverpool."

Necessity of two sets of pails.

He points out that it would be absolutely necessary to have "two receptacles for each house, one to use and one to clean." "But it may be said that there is no necessity to return always the same utensil. Then my answer is, that the disgust, the fear, the panic during epidemics of small-pox, of scarlatina, or of Asiatic cholera, that infection would be brought to one's home by these means, would soon control all municipal authority, and upset the whole scheme." *

Dr. Trench here assumes that the pails are carried away, contents and all, by the scavengers; a perfectly just assumption, as the plan of emptying them into the scavenger's cart, cleansing and replacing them on the spot, would create such a nuisance that it would not be endured. But his objections do not apply so forcibly to the ash or earth closet systems, as a like proceeding in these cases is not, *i.e. ought not to be,*

* First Report, Rivers Pollution Commission, 1868, vol. ii. p. 306.

attended with nuisance, and so the receptacles, not being carried away, cannot get changed.

Mr. Menzies says of the pail system, that "it can never be adopted near dwellings of the better classes, for the sight and smell are so exceedingly nauseous that they could not be endured. The removal of the matter is indeed at all times a filthy operation, and the iron pans when empty smell even worse than when they are full, as there is then a greater surface exposed." * Nuisance.

The trough latrines of Glasgow and Edinburgh may be conveniently considered here: they are in effect the pail system adapted to large collections of people. A long fixed iron trough, slightly inclined towards one end, runs along under the seats of a row of closets; it is provided with a little water, just enough to make the contents run easily, and it receives the total urine and excrement of the persons using it. In the Glasgow factories there is one on each of the four stories, and it is used by 180 to 200 persons; the contents are emptied once or twice a day down a vertical pipe into a large closed tank placed close to the ground, and holding 80 gallons, or about a day's produce; this is emptied by means of a 12-gallon two-handled pail into a closed cart, and the contents "carried away without very much offence." Trough latrines.

These must not be confounded with trough water-closets, which will be described in their proper place. They differ from them in this fundamental and essential point, that they are not connected with the sewers, and therefore require special scavenging arrangements. Not trough water-closets.

Iron trough-closets of the above description, including ash-bins, cost "for two persons £23, for three persons £32, for four persons £41."

* Management and Utilisation of Sewage, p. 6.

THE EUREKA SYSTEM.

In the *Journal of the Chemical Society* (March 1866) Messrs. Lawes and Gilbert have described this system as it was carried out at Hyde, near Manchester. A box containing "some disinfectant or deodorising mixture" was placed under the privy-seat, with instructions that no slops were to be put into it, left for a few days, then covered by a tightly fitting lid and carried off, and a fresh one put in its place. These covered boxes were placed in a close cart, and carried away to a manure manufactory near to the town, where their contents were treated with more disinfecting fluid, concentrated by distillation, and ashes added, the whole making a not very valuable manure (containing only between 1 and 2 per cent of ammonia), one that would certainly not bear the cost of carriage "beyond the distance of a very few miles." The inhabitants considered the works a nuisance. Dr. Trench, in 1864, visited Hyde to inspect this process, and says that it was, in his opinion, in all its details, "a shocking and unmitigated nuisance." Dr. Beecroft, of Hyde, after having mentioned his own belief that the system had been the means of spreading infectious disease, and would be highly dangerous during an epidemic of Asiatic cholera, thus concludes: "If the Eureka Works were removed so as to do away with the excessive stink which we receive from them when they are in full work; if the boxes were numbered so that each house could always have its own returned; if the boxes were made or lined with a non-absorbent material in the place of the porous wood, as is the case at present; and if the boxes were emptied more frequently (daily

Plan at Hyde.

Poor manure.

Nuisance.

when infectious disease existed), the system would be superior to the old ash-pits, though not to be compared with water-closets" (*First Report R. P. C.*, 1868, vol. ii. p. 306). We find, from the report just quoted (vol. i. p. 51) that "the plan has at length been abandoned for both of the reasons referred to by Messrs. Lawes and Gilbert," viz. the alleged nuisance and the worthlessness of the manure. Has been abandoned.

THE GOUX SYSTEM.

This system, called also the "Patent Absorbent Closet System," consists in a modification of the ordinary pail closet by the lining of the tubs with some kind of absorbent material. Absorbent materials. The prospectus of the patentees states that "all kinds of vegetable and animal fibrous matters, useless for other purposes, are used as absorbents," and these are "to be mixed in such proportions as may be most convenient, together with a small percentage of sulphate of iron or sulphate of lime." These matters are pressed closely to the bottom and sides of the tub by means of a cylindrical mould, which is afterwards withdrawn, leaving, of course, a cavity in the centre of the materials. Ordinary midden closets can be easily converted into those suitable for this system by cleaning out the ash-pits, filling them up with engine ashes or other dry refuse, paving the floor under the seats, and covering them with slated roofs; in fact, by the alterations required for the ordinary pail closet. Conversion of ordinary midden closets. A separate tub is required for ashes and dry rubbish, but chamber utensils and so forth may be emptied into the tub under the privy-seat. The pails require to be removed weekly, or twice a week, and this is Removal of tubs.

easily done by making the privy-seats movable. The patentees state that "for the interior of mansions, dwelling-houses, schools, unions, hospitals, and factories, an adaptation of the system has been designed which provides for the removal of the collected matters without the trouble and inconvenience of carrying them downstairs. This plan will cost less than the ordinary water-closet, and can be applied wherever such closets can be fixed." They also state that "a closet on the Goux system cannot be made uncleanly except by the most positive wilfulness." This would not, however, seem to be the conclusion to which Dr. Buchanan came in his inspection of the working of this system at Salford. He found that the absorptive materials appeared to be of very little use, and that, in fact, whenever the pails had been in use for more than two or three days, the absorptive capacity was invariably exceeded; that wherever they had been in use four or five days, or for a week, the pails were two-thirds or more filled "with liquid dejections, in which the solid excrement was floating," and that this was not always from the chamber utensils being emptied into them, although it must be remarked that this procedure is sanctioned by the promoters of the system. There is no doubt, however, that although the Goux system cannot be accounted among the "dry" methods of treating sewage, yet it is much superior to any form of midden system. When the closets are well managed they are generally clean, and afford no offensive smell, and they entirely prevent any pollution of the soil near houses. The Goux plan has also been applied to public urinals, but in this case the absorbent materials are only professedly "a filter through which the liquid urine passes

Absorptive materials of very little use.

Urinals.

into the receptacle below." This receptacle contains a small quantity of sulphate of iron, with the object of preventing fermentation, and the urine collected in it is subsequently used in the manufacture of the manure in connection with the contents of the pails. (See *Twelfth Report M. O. P. C.*, p. 116.)

The alteration of a midden closet into such a one as has been above described costs 35s., and a set of tubs 10s.; each tub on an average contains 84 lbs. of dejections, being calculated to hold 120 lbs. Two men and a horse can remove 600 tubs in a week, or 22½ tons of contents, the cost being £1 a week for each man, and £1 a week for the horse; say 2s. 9d. a ton for the cost of removal. For this crude material from 5s. to 6s. a ton is given by the farmers, but when a manure is prepared from it by the plan originated by Mons. Goux, it sells for £2 a ton, and is "considered cheap at the price." The method of preparing the manure from the stuff collected is to spread it on a floor and sprinkle it with a little sulphuric acid, when, "after a certain amount of fermentation and consequent destruction of the fibrous matter, the whole becomes a homogeneous, inoffensive, but feeble manure, which may be very fairly described in the words used by Messrs. Lawes and Gilbert about the Eureka failure." (*First Report R. P. C.*, 1868, vol. i. p. 51.) Expenses. Feeble manure.

Of this and all similar systems it has been well said, "not only that it is but a part of the excrementitious matter which is dealt with, but that even as regards that portion of the excrement which they do remove, they so entirely depend upon efficient cleanly superintendence and direction, that wherever they have merely had the average man to work them, they Too much supervision required.

have failed. Moreover, this very frequent collection of filth by hand from houses, and its removal, sometimes through the cottages themselves, almost necessarily under the eye and nose of the household, whatever may be the importance of the economic object aimed at, is universally condemned by our domestic habits as nasty and offensive. They can never be an entire success, and, in competition with the water-closet, a jury of average householders will certainly condemn them for lack of cleanliness and comfort." (See the last reference.)

Offensive methods.

UTILISATION.

As false ideas with regard to the composition of human excreta are very widely spread, we think it advisable to give the results obtained by the comparison of a great number of analyses of fæces and urine; they are taken from a paper read by Mr. Lawes, F.R.S., before the Society of Arts, 7th March 1855.

Composition of excreta.

These analyses are only sufficiently complete in the case of males from fifteen to fifty years of age, the mean amounts in ounces of the various constituents during twenty-four hours being as follows:—

	Fresh Excrements.	Dry Substance.	Mineral Matter.	Carbon.	Nitrogen.	Phosphates.
Fæces .	4·17	1·041	0·116	0·443	0·053	0·068
Urine .	46·01	1·735	0·527	0·539	0·478	0·189
Total .	50·18	2·776	0·643	0·982	0·531	0·257

From this table it will be seen that the amount of valuable matter contained in the urine is greater under every head than that contained in the fæces; the nitrogen being no less than nine times, and the phosphates nearly three times as much by weight in a given time. It should be added, however, that some analyses made by Messrs. Lawes and Gilbert show that the amount of phosphates in the fæces is not nearly so small as that above given, and is, in fact, not far below the amount contained in the urine, the relative amounts in ounces during twenty-four hours being as follows :— Amount of phosphates.

	Fæces.	Urine.	Total.
Man, 46 years . .	0·147	0·178	0·325
,, 50 ,, . .	0·148	0·213	0·361
Mean of 3 boys, 5, 10, & 12 years . .	0·057	0·076	0·133

The total amount of fæces as given above is rather less than the amount determined experimentally by Messrs. Lawes and Gilbert, and we may consider that the weight of the urine passed is nine or ten times as great as that of the fæces; now, as the total urine is worth about six times as much as the total fæces (see below), it follows that a given weight of fæces is more valuable than the same weight of urine in the proportion of nine or ten to six. Comparative value of urine and fæces.

While remembering that the fæces are more valuable than the urine, *weight for weight*, we must not forget that the urine passed by an individual in twenty-four hours is worth six times as much as the fæces passed in the same time.

It has been shown by Messrs. Lawes and Gilbert from their own calculations, and also from the results obtained by Messrs. Hofmann and Witt, and by Dr. Thudichum, that the average amount of ammonia voided annually by an individual of a mixed population of both sexes and all ages, is, in urine 11·32, in fæces 1·64, total 12·96 lbs.; and that the estimated

Value of excreta.

money value of the total constituents is, in urine 7s. 3d., in fæces 1s. $2\frac{3}{4}$d.—total 8s. $5\frac{3}{4}$d.* We note at once the comparative worthlessness of the fæces in an agricultural point of view, and are thus prepared to see any plan fail, economically speaking, which does not make it its especial business to utilise the ammonia and other valuable manurial constituents of the urine.

(A.) MIDDEN SYSTEM—FRENCH "FOSSES."

Sold to farmers.

In country places the filth of the ash-pits, etc. is usually sold to farmers, who come and fetch it away, and sometimes it seems to sell well. Thus, at Stratford-on-Avon the manure is said to be "readily disposed of." It is, however, allowed to accumulate until it suits the convenience of the farmers to fetch it away, and in many places they refuse to take it at all. This takes place in like manner in the lower neighbourhoods of towns, where "the refuse of the courts and alleys is reserved in the necessary pits till the accumulation is very considerable; the inhabitants then sell it for a few shillings per load, and divide the amount so obtained amongst themselves."

Not a good manure.

Although many of the disadvantages of the midden system may be obviated by improvements in the construction of the pits, etc. it can only answer in exceptional cases, as most of the urine is lost and the manure obtained is only well suited for heavy clay soils; for most soils the admixture with ashes renders it comparatively worthless.

And in a town in which it has been most per-

* This quantity is considered by Messrs. L. and G. to be too high when applied as a means of calculating the value of sewage: they are of opinion that in that case 10 lbs. of ammonia per head per annum, with a value of 6s. 8d., would be a more accurate estimate.

severingly employed—Manchester—it has failed in an economical point of view; on this head Sir Joseph Heron, the town clerk, says, in his evidence before the Rivers Pollution Commissioners: "It is true in Manchester, as well as in Liverpool and in other places, that the expense we incur in removing the night soil is by no means returned to us by anything that we obtain for it, and we often have to carry it at a very considerable loss. *In no case is it found that it is paying.*" Does not pay.

With regard to the midden system, we obtain some additional information from the Appendix to the Report of the British Association Sewage Committee of 1869-70. (*B. A. Report*, 1870, p. 56.)

The town of Bury, in Lancashire, is almost exclusively a privy and ash-pit town; the population is about 40,000.

No special treatment is practised previous to the removal of the contents of the privies beyond the addition of ashes. This accession of ashes, together with the necessity of conducting its removal at night, materially reduces the value of such mixture as a manure, and the whole quantity only yields an annual return to the Commissioners of £100. Value of midden refuse.

The street sweepings are also removed by scavenging, and cost the Commissioners not less than £629 : 11 : 8, while, from the want of some yard or other storage ground, they have to be disposed of to farmers at their own price, and only yield the insignificant return of £25 to £30 per annum.

The "remarks by a sub-committee, consisting of Messrs. Grantham (chairman), Corfield, Hope, and Williamson," are to the following effect:—

The figures obtained in Bury of the ash-pit system, as carried out there, prove that financially it is, so far as Bury is concerned, a total and complete failure, as the gross return is only a little over one half-penny per head of the population annually. Of course it is not fair to judge of a general system from a particular instance, and the subject should be further investigated. Failure at Bury.

Some analyses of the sewage "show that although the sewage from a town managed on the Bury system is weaker, and therefore less valuable and proportionately more difficult to deal with than the sewage from a water-closeted town, yet that its purification is just as imperatively necessary."

Gain at a few towns.

In only three towns of the two hundred tabulated by this committee is a gain obtained from the sale of midden and cesspool contents and other refuse, over and above the cost of scavenging. These are Dundee, which has already been noticed, where £630 a year, or 1⅓d. per head per annum, is made; Stockton-on-Tees, with £100 a year, or 1d. per head per annum; and Fareham, with £7 a year, or ⅓d. per head per annum.

Loss at most places.

In all other recorded cases the scavenger receives a payment in money, as well as the refuse, for doing the required duties. The greatest losses are experienced at Liverpool, where the scavenging costs £41,866 a year, or 19·7d. per head; and at Scarborough, where it costs £2050, or 22·4d. per head. At Malvern the cost amounts to 18·0d. per head; at Oldham, 13·1d.; at Bradford, 19·3d.; at Rochdale, 11·2d.; at Bridgenorth, 10·2d.; at Torquay, 10·2d.; at Newcastle, 17·5d.; at Cardiff, 11·3d.; at Llanelly, 15·3d.; at Aberdeen, 11·2d.; and at Edinburgh, 11·7d. per head per annum. (*N.B.*—The above sums are in pence and decimals of a penny).

From the Third Report of the Rivers Pollution Commissioners, 1868 (p. 7), it appears that:—

Midden system at Leeds.

There are in Leeds about 6000 water-closets, besides a number of trough and tank closets, and some 10,000 privies, middens, and ash-pits, all of which are connected with the sewers. These are cleaned periodically under the direction of the Sanitary Committee of the Corporation, at a cost of about £12,000 a year, and the Corporation receive about £6500 a year for 70,000 tons of refuse; the cost of cleaning them exceeding the amount received for the manure by £5500 a year. This scavenging process, which thus costs about 1s. annually per head of the population, while about 6½d. a head annually is obtained for the excrementitious matter removed, is at the same time most offensive. "The cleaning of the privies, middens, and ash-pits is complained of as a nuisance affecting the health and comfort of the inhabitants. The stench in Leeds from 10 P.M. till 4 A.M., while this operation is going on, is described as something fearful." Nuisance.

These figures show that, as we have before stated, the midden and ash-pit system can only be an economical success in exceptional cases ; as a matter of fact, it usually entails a considerable annual expense.

French *voiries.*

In France the contents of the *fosses permanentes* and *fosses mobiles* are not usually utilised without preparation, but are carried away in the *tonneaux* to some distance from the town, where they are emptied into the highest of a series of basins ranged one above another ; here they are exposed to the air for some time, and while the liquid parts run away into the lower basins, the undissolved solids subside in the higher ones. The liquids are reduced in quantity by spontaneous evaporation, but they have for the most part to be pumped away, generally into the nearest watercourse ; sometimes, however, they are evaporated, mixed with sulphuric acid and sulphate of ammonia thus prepared. The establishments in which this latter process is carried on have been placed in the first class of *établissements dangereux ou insalubres,* the reason being that they cause an *odeur désagréable et portée au loin.* The solid part which subsides is dug out of the pits, further dried by being spread out on a large surface of ground and stirred about continually, piled up when nearly dry in immense heaps, and left for a year at least, often for several years ; it is then sold under the name of *poudrette.* " It has then the aspect of a grayish-black earth, light, oily to the touch, very friable, and spreading a peculiar odour, disagreeable and nauseous, which is not that which the matters

Liquid part mostly lost.

Poudrette.

which compose it exhale in their native state, or even before their perfect desiccation." (*Parent Duchatelet.*)

The *poudrette* prepared from the deposit in the lower pits is especially sought after by the farmers, as it contains the finer particles which have escaped precipitation in the higher pits, and at the same time less useless material.

In Paris the business of removal and preparation of the manure is let out to a contractor, and the city would appear to make a gain out of the transaction, *i.e.* the public funds are benefited by it; but not so the ratepayers! They pay a considerable sum for the emptying of their cesspools, 8 fr. a cubic metre, 15 fr. for a *fosse mobile* (Tardieu); and Mr. Krepp calculates that the *poudrette*, which sells only at 47 fr. 50 c. a cubic metre, really costs the city 146 fr.

Loss to the public.

(B.) PAIL SYSTEM.

In this system we have the fæces and urine pure, without any admixture of earth, ash, or water, except in some cases to a trifling extent. The evidence generally shows that this plan can be made to pay, and indeed generally does pay its cost at any rate.

Can be made to pay.

"In the town of Gröningen the yearly profit amounts to about £1600; in Antwerp it is £2700, at Ostend £700. In Strasbourg the cost of removal is only just covered by the sale of the manure. The sale of the refuse from the barracks at Carlsruhe, where 2800 men were quartered, has realised a profit of £300 a year, and the attendant expenses amounted to about £40 a year." Sometimes, however, the expenses exceed the income derived from the sale of the manure: "thus, in Stockholm, with a population of about 150,000, the expenditure amounts to £35,000 a year, and the income derived from the sale of the refuse as manure is £33,000 a year." * Various examples.

In Nottingham the contents of the boxes are sold at from 3s. to 4s. a ton; this brings in £4000 a year, while the cost of scavenging is £6000. At Rochdale the plan scarcely pays its expenses at present, as there are only 580 pail closets, and so the expenses are relatively high. If, however, all the 4000 midden closets of the town were changed into pail closets, Mr. Alderman Taylor calculates that the profit to the town, on the sale of the manure at the present rate (15s. a ton), would be £9 a week, or £468 a year. He, how ever, anticipates a higher value for the manure (1870).

In Glasgow the estimated value of the contents of the pails, troughs, etc., plus the ashes and street sweepings, is £18,000 a year, while the cost of cleansing the city is £27,000; from which we see at once that the cost of removing the excrement of a large city by cartage is enormous. Cost of scavenging.

In the prize essay by MM. Renard and Frontault, published in 1870, in the "Annuaire de la Société des Agriculteurs de France," an interesting account is given of the success which attends the careful employment of this system in the department of the Alpes-Maritimes. Success of pail system.

The fæcal matters are collected as they are voided, before fermentation, in *tinettes* of 60 litres (about 13 gallons), which are emptied at the foot of the trees into two holes, 18 inches broad and 10 inches deep, placed one on each side of the tree; these are then covered in with earth.

This process is especially applied to orange trees, which are planted 400 to the hectare (nearly 2½ acres). The fæcal matters are often paid for at the rate of 5 or 6 francs per cubic metre (3s. to 3s. 7d. per cubic yard), even at the spot where they are produced, in spite Value of excrement.

* First Report of British Association Sewage Committee, 1869.

of the quantity of water which they contain. A household averaging four persons produces about 3 cubic metres (nearly 4 cubic yards) annually, from which it obtains an income of from 15 to 18 francs (12s. to 14s. 5d.), a very valuable thing for poor families.

At Grasse and at Nice human manure is the manure *par excellence.* It is used in the cultivation of corn, of green vegetables, and of flowers to be employed in perfumery, notably violets and roses; but after it has begun to ferment. The peasants exhibit an astonishing zeal in collecting it; one sees them walk a league, *pour ne pas perdre leur déjection*, and when they buy fæcal matters in the town, generally in casks, they do not omit to taste them, in order to ascertain their degree of concentration. They keep them in large jars of 2 or 3 hectolitres (44 to 66 gallons), placed at various parts of their fields. This plan is, moreover, easily managed in that country, where, as is well known, a plot of 2 hectares (nearly 5 acres) is a large one.

Collected by peasants.

With this manure, combined with irrigation and the sun's influence, they obtain a fabulous produce; a certain farm of 17 hectares (42 acres) yields 45,000 francs (£1800) nett, annually.

Cultivation of scented flowers.

It will be observed that in these countries human excrement is especially used for plants from which scents are manufactured, a flat contradiction to the counter statements that have been made on this head.

Our authors also quote largely from a report by M. Simon, who was sent by the French Government on an agricultural mission to China, where, as has been already stated, the same plan has been at work from time immemorial. As an answer to how it is that so dense a population can be supported in a country, M. Simon says:—

Reason of prosperity of China.

The reasons of it are manifold. Without doubt, the climate, the industry of the Chinese, even their sobriety, and the fertility of the soil, to a certain extent explain it; but the principal reason of it is, assuredly, the skill with which the manure is collected and distributed.

Then, after describing the extreme care given by the Chinese to their plants, he adds:—

The liquid form in which one most often sees the manure in China renders it especially fit for this use, so that it can be distributed during the growth of the vegetation as well as before it. Some of the manure is not, however, naturally in so convenient a form, but the Chinese reduce it to the liquid or to the pulverulent condition by special manipulations.

M. Simon adds that human manure is applied to all crops, and that "sometimes it is placed at the entrance to the carriers, and the water dilutes it and carries it along," while at others it is mixed with an argillaceous earth, and dried in the form of small bricks; it then goes by the name of *taffo*, and, according to the evidence of one traveller, "has no other odour than that of the violet!" Utilisation of excreta.

This method, no doubt, appears nasty to us, but M. Simon well says of it, "I ask myself if it would not be better to offend the noses of the passers-by than to throw into the river quantities of excremental matters which by their decomposition become veritable causes of disease (*infections morbifiques*) to the people lower down."

MM. Renard and Frontault describe a number of processes for manufacturing portable and inodorous manure out of the crude contents of the French *fosses*, the most notable being those of the *Compagnie Chaufournière de l'Ouest.* The solid matters from the *fosses* are mixed with quicklime, and a manure known as *la chaux animalisée* manufactured; the liquids which pass through the *séparateur* of the *fosse mobile* are received in a compartment which contains powdered slaked lime, by which they are absorbed and *la chaux supersaturée* formed: or the urine is collected and allowed to stand for two hours in vessels with lime at the bottom; it then becomes inoffensive, and is known as *les urines imputrescibles*, while *taffo*, *taffo enrichi*, and *phospho-taffo* are dried excremental matters mixed with various kinds of refuse, and with other substances which add to their value as manure. Manufactured manures.

It is not necessary for us to enlarge upon these or other methods of treating crude excretal matters, especially as there can be no doubt that the most profitable way to employ them is to apply them at once to the soil without any preparation at all.

Liernur's system.

In the *Engineer* of 7th December 1866, a full description of Captain Liernur's system (described at page 237) is given; from this it appears that the manure is to be sent in air-tight barrels to the farms, and there applied to the land during the process of ploughing; the plough is so constructed that the barrel can be placed on it, and the manure is discharged from the bung-hole of the barrel into the furrow made by the ploughshare, and immediately covered in with earth by a kind of shovel which trails behind. A special kind of plough adapted for manuring meadow land is thus described:—

Special ploughs.

A sort of knife makes a running incision in the sods, while a hollow foot attached to it makes a cavity under them. In this cavity the manure is poured, through a hole which passes through both the knife and its foot. After its passage the sods close immediately again, partly through their own weight and partly through elasticity. A layer of earth should be left between the sods and the manure, to decompose the latter, and prevent its hurting the grass plants.

These plans are worthy of the attention of towns where the pail system is at work.

New system of dealing with town refuse.

A new system of dealing with refuse has come into operation in many towns, which obviates many of the difficulties and dangers attending the accumulation and sorting of vast heaps of semi-putrid refuse, which is still carried on in London, often in close proximity to inhabited houses. By this method also, it has been found possible, where the pail system is in use, to evaporate the pail contents and produce a dry portable manure, from the heat generated by the combustion of the cinders and ashes collected in the town, without the use of any coal whatever.

Pail contents can be evaporated.

In Dr. W. Sedgwick Saunders' Report upon "Some New Methods of Disposing of all kinds of Refuse by Cremation," 1881, we find an account of the system which was then being introduced into Warrington.

Disposal of ashes.

The ashes, etc. collected in tubs, are screened in an automatic cinder screen; the fine ash is mixed with such portion of pail contents as will furnish a manure sufficient to satisfy the local demand; the coarse ash is discharged into a form of furnace, called a "destructor," which is made to destroy and reduce any refuse material that contains only a small portion of combustible matter. The heat generated by the combustion passes under and through a multitubular boiler, and generates steam for furnishing the power required for working the whole of the machinery. The clinkers from the "destructor," if not required for other purposes, are passed into a mortar mill, which reduces them to powder that can either be sold as sand, or made, by the addition of lime, into an excellent and tenacious mortar.

Disposal of street and market refuse.

The sweepings from the markets and streets are passed through a "carboniser," a furnace which converts all vegetable material into charcoal. The charcoal produced is a very powerful deodorant; and it was proposed to use a portion of it in each pail, previous to its leaving the depôt, to deodorise the matter collected; the remainder to be sold.

Disposal of pail contents.

The contents of the pails are mixed with a small portion of acid, to fix the ammonia, in an air-tight store tank, where the thicker portion of the material settles to the bottom. The thin part of the contents of the tank is drawn off into two evaporators, which are tall cast-iron cylinders, each containing near its lower end a drum-shaped heater, precisely resembling a multitubular steam boiler. These cylinders are partially filled, and the heating drums are covered with the thin liquid; steam is introduced within the heating drums, and the liquid becomes partially concentrated. When the contents of these cylinders are sufficiently concentrated and have lost, by evaporation, the greater portion of their water, they are drawn off into a "Firman's dryer," and the thick portions of the pail contents which settle in the store tank are also admitted into the dryer. This machine consists of a steam-jacketed horizontal cylinder, traversed by a steam-heated axis, and by steam-heated revolving arms, and furnished with scrapers to keep the inner surface of the cylinder free from accumulations of dried excreta. The pail contents are admitted into the dryer at the consistency of thin mud; after treatment they emerge as a dry powder, resembling guano in appearance and quality, and estimated to be worth from £3 to £6 per ton, dependent upon analysis. The odorous gases given off during the process are all passed through the destructor fire and destroyed. From the time the liquid material enters the store tank, there is no opportunity for odour to escape into the air, as it is kept closely under cover, until it finally emerges as a dry powder.

Pail contents converted into a dry powder.

All odorous gases given off are burnt.

The "destructor" and the "carboniser" are the inventions of Mr. Alfred Fryer, who also invented the process by which the collected ashes and cinders are alone sufficient to furnish the heat necessary to evaporate the contents of the pails. The arrangement by which this is effected is as follows:—The steam and vapour, which are driven off from the concentrating vessel and the "Firman's dryer," instead of being allowed to escape into the air or to be condensed by

Process for evaporating pail contents by means of heat from ashes and cinders only.

cold water, are used to furnish heat to the large or main concentrating apparatus, which is kept boiling at a low temperature. This is effected by conducting the boiling below atmospheric pressure in a vacuum, which is maintained by an air-pump attached to the steam-engine. This larger vessel is in fact a vacuum pan. The apparatus is so connected with tubes and valves that the "Firman's dryer" may also be worked under vacuum, if necessary.

Disposal of refuse at Manchester

At Manchester a portion of the town refuse is dealt with at the corporation's sanitary works at Holt Town. The cinders collected are mainly used as fuel for the furnaces of the boilers which work the machinery, effect the evaporations, etc.; the animal matters are converted into dry manure, soap, candles, and lubricating grease; and the clinkers from the furnace are made into mortar, bricks, and concrete.

Composition of the manure.

The animal matters from which the manure is made include human excreta (pail contents), slaughter-house refuse, bones, dead animals, fish, etc. This manure contains ammonia 2·73 per cent, phosphoric acid 2·36 per cent, alkaline salts containing 25 per cent, of potash 4·39 per cent, and moisture 15·07 per cent. It is sold at £3 per ton.

A system similar to the above is in operation at Glasgow. (See Paper by John Young, Inspector of Cleansing, on "The Scavenging of Towns," published in the Transactions of the Sanitary Institute of Great Britain, vol. v. 1883-84.)

Adoption of system in various towns.

In Dr. Sedgwick Saunders' Report, before mentioned, it is stated (p. 82) that destructors and carbonisers for the cremation and utilisation of town refuse had been or were being supplied to the following places, viz.:—Leeds, Bradford, Manchester, Warrington, Rochdale, Stafford, Bolton, Birmingham, Blackburn, Rotherham, Derby, Bury. A number of towns had also decided to adopt them, including Nottingham, and others were in treaty.

The deputation from the Commissioners of Sewers (city of London) which visited the works established at Leeds, Bradford, Warrington, and Manchester, in 1881, came to the unanimous conclusion that :—

Conclusions of the deputation.

> The system recently inaugurated is sound in theory and desirable in practice ; that it has already passed beyond the experimental stage, and that it offers enormous advantages upon sanitary grounds, and is not to be despised for its commercial results ; not only did they see a work consisting of poisonous and disgusting elements dealt with, and satisfactorily disposed of, without nuisance of any kind, but learnt that products having a marketable value can be, and are, produced without any infraction of true hygienic principles, whilst at the same time they may have the effect of materially reducing the expenses. (Dr. Saunders' Report, pp. 81, 82.)

The advantage in a commercial point of view of the pail or tub system over the midden system is, that it produces a valuable manure, which can be made, as at Salford, to pay more than the cost of collecting it. It is the system which has answered so well in China and Japan for so many centuries, but it is one which accords in no way with modern ideas of cleanliness, and which could never be introduced into the better quarters of any town ; for the lower classes of habitations it is a great improvement on the old midden heaps, cesspools, etc., as it necessitates the daily or even more frequent (as at Edinburgh) removal of excremental matters, which can be easily disinfected if necessary.

Has succeeded in the East.

It must, however, be considered to be the only plan that we have yet examined that can be made even to pay its expense as a general rule.

SANITARY OBSERVATIONS ON THE IMPROVED MIDDEN AND CESSPOOL SYSTEMS.

It having been already shown that accumulations of excretal and other filth afford a nidus for various diseases, it need only be pointed out here that the sanitary advantage possessed by these systems varies precisely with the frequency with which they provide for the removal of the refuse matters, and with the perfection of the means taken to prevent their decomposition. Frequent removal.

Wherever one of these plans has been introduced, a step in the right direction has been made, and the necessity of the speedy removal of excrement has been acknowledged, except indeed in the case of the large cemented cesspools, *fosses permanentes,* in which, however, every precaution is taken, abroad at any rate, to prevent the contamination of water or air; with what result we shall soon see.

Any state of things is better than the one described in our first chapter, and the frequent removal by hand and cart, although annoying, affords less nuisance and much less positive danger than the stinking heap of putrid filth in the ordinary midden heap or cesspool.

The simple pail or tub placed under the privy-seat, and removed daily, or even twice a day, is the most thoroughgoing of these methods, but, to say the least of it, a very nasty one, and a very troublesome one too. The French *fosse mobile*, with its *séparateur*, is by far the best plan for keeping excremental matters intact for a few days, and is much superior to any pails or buckets lined with absorbent materials or provided with disinfectant matters. But this, though a vast improvement, as pointed out by Parent Du- Pail system best, but nasty. *Fosse mobile.*

chatelet, on the *fosse permanente*, is, with most of the systems now under consideration, a mere make-shift to obviate the nuisance and expense of too frequent removal, while at the same time effectually preventing long storing.

The question in fact to be solved would appear to be, with all the methods which require hand and cart labour, how can the refuse matters be kept as long as possible without being positively dangerous to health ? Instead of, as it should be, how can they be got rid of as fast as possible ?

Wrong principle.

This consideration at once stamps all methods of removal by scavenging, and must of itself bind them to a false principle, and lead to their condemnation; indeed, they are only commended by the fact that they do not utterly waste the valuable manure with which they have to deal. The midden-pits are improved, from a sanitary point of view, as they depart farther and farther from the old conventional ash-pit: it is found practically, however, that they cannot usually be kept dry, and so they have to be drained into the sewers.

Midden-pits.

Gases in cesspools.

The large cesspools become filled with fœtid gases, containing a large proportion of sulphuretted hydrogen, and many were the cases of asphyxia caused by it during the emptying of the *fosses permanentes* by hand and bucket; this asphyxia, which the workmen call *le plomb* (probably from the sense of extreme oppression of the chest), and which occurs also to the workers in sewers, is, according to Parent Duchatelet, not so common as it has been stated to be. People exposed habitually to such an atmosphere (*vidangeurs, égoutiers, gadouards*) suffer also from headaches, and from ophthalmia (*la mitte*); their term of life does

Influence on diseases.

not, however, appear to be shortened, probably because those who are not of very strong constitutions give up the work at once. Parasitic diseases and most skin diseases are very uncommon among them, and they are said by the above authority to be remarkably free from intermittent fever and from cholera. He gives also an instance of three young women who had been pronounced consumptive by several physicians, and who were perfectly cured by working at the *poudrette*. Query, would they not have been as much improved in health by any *out-of-door* work? Venereal diseases are, however, undoubtedly, according to the testimony of Hallé and of the last-named observer, aggravated to a remarkable degree by this foul atmosphere, and "those who, having one of these diseases, persist in working, perish inevitably."

With regard to the symptoms of the asphyxia, they vary according as it is caused by want of oxygen or by the presence of a notable quantity of sulphuretted hydrogen. In the first case there is a difficulty of breathing, which gets worse and worse—it is a true suffocation; in the second, "the individual is seized suddenly, and dies instantly; or, if the quantity of deleterious gas is too little to bring instant death, the asphyxiated person, suddenly losing consciousness, is taken with convulsive movements or other very grave nervous disturbances, and it is only after several days that he recovers a perfect state of health." (*Parent Duchatelet: Hygiène Publique*, vol. i. p. 268.) Forms of asphyxia.

Sufficient evidence has already been adduced to show that an atmosphere tainted with the offensive gases given off by decomposing refuse is, even when much diluted, deleterious to health; but we may here quote a passage from the Health of Towns Reports

Cases in England.

(1844) which forcibly illustrates this point:—"It is not a great many years since four men fell victims to the poison whilst engaged in clearing out a privy near Brompton, and still more recently an accident of a similar nature happened at Clapham. Twenty-three children belonging to a boarding-school at that place were simultaneously attacked with violent irritation of the stomach and bowels, convulsive twitchings of the muscles, and excessive prostration of strength; and two of them died in about twenty-four hours. The symptoms were ascribed by the medical attendants to the inhalation of sulphuretted hydrogen from the contents of a foul cesspit which had been scattered over a garden adjoining the children's playground. Although these effluvia are breathed by the inhabitants of our courts and back streets in a state, of course, of extreme dilution, we cannot suppose that they are on that account entirely harmless. What in a concentrated form is so very deadly, must, in a diluted state, be injurious to health." (*Loc. cit. First Report*, vol. i. p. 139.)

Effect of foul gases on children.

Disease caused by *poudrette*.

The French *poudrette* itself, though inoffensive in a dry state, undergoes a kind of fermentation when moistened; and one of Parent Duchatelet's most remarkable memoirs contains an account of a disease that broke out on board the "Arthur" (a boat which had been loaded with *poudrette* on a rainy day), "of which half the crew perished, the rest arriving at their destination in a deplorable state of health." The workmen who removed the stuff from the vessel were also seized by the disease, which, from a most accurate description given of the symptoms on a similar occasion by the same author, would appear to have been typhoid fever; he says it had "all the symptoms of one of those grave diseases known under the name of adynamic fever" (*Hygiène Publique*, vol. ii. p. 257, etc.) These cases should be kept in mind during the transportation of any manure that requires to be kept dry.

The sanitary results of the midden closet system are not, moreover, what were contemplated by its supporters. The average death-rate of Manchester, where it has been carried out with great attention to detail "for fifteen years, as reported by Dr. A. Ransome and Mr. W. Royston, was 32 per 1000, or, excluding certain healthy suburban districts, 34 per 1000; while in 1865, an exceptionally bad year for epidemics of small-pox, scarlatina, etc., it was 39 per 1000. It is also stated that the infant mortality of Manchester is higher than that of any other place in the kingdom, this fact being regarded as an invariable sign of sanitary neglect."

Manchester mortality.

" It is believed that much of the unhealthiness and mortality in Manchester, especially among children, may be ascribed to the atmospheric pollution caused by the present privy and ash-pit systems." (*British Medical Journal*, 18th June 1870.)

CONCLUSIONS.

We have now dealt with the treatment of liquid manure, as such, in the various forms of cesspools, pails, tubs, and so forth, without the addition of any notable quantity of extraneous matters, whether with a view to the dryness or the disinfection of the contents; and also, on the other hand, with its treatment by admixture with a sufficient quantity of ashes and other refuse (as in the various forms of midden-pits and closets) to render the whole a more or less solid dry mass. We have seen that the former of these systems is as a general rule connected with a considerable amount of nuisance, either in the collection or removal of the excremental matters, or in both of these particulars, and that, although one modification of this system has practically succeeded in an economic point of view in certain countries, and even in a few of our own towns, it can never be looked upon as a solution of the question of the removal of excrement which can be adopted generally by the community as a final one, or even as a suitable one.

Nuisance.

The pail system presents several advantages for poor town districts. It may safely be employed for excrement removal if movable pails of defined construction be used, and be changed every day for fresh pails. Such a system, involving similar construction or constructive alterations as are required for the toleration of a midden system, offers advantages over the latter in regard of facility for frequent removal of excrement, in regard of safety from nuisance, and probably in regard of profit in disposing of excrement as manure. (*Twelfth Report M. O. P. C.*, p. 140.)

With regard to the second of these systems, we have seen that it is almost invariably connected with great nuisance, both in the storing and in the removal of the contents of the pits or closets, and that it possesses the additional disadvantage of the necessity of disturbing these contents in order to remove them.

Frequent removal.

The midden system may be modified so as greatly to reduce nuisance and danger from it. We have described the form of midden-closet which we think presents fewest objections. We cannot speak of satisfactory safety in the use of even this form of midden-closet, partly because we hardly expect to see it carried out with daily emptying, and partly because the materials of the midden would probably be retentive of some excremental matters; but if under certain circumstances middens, constructed as above, should be tolerated, it would, we think, be scarcely less than essential, first, that they should, if in a densely populated neighbourhood, be emptied daily, or under other circumstances at least once a week, and secondly, that the arrangements for excrement removal should be wholly in the hands of efficient persons appointed by the sanitary authority. (*Twelfth Report M. O. P. C.*, p. 140.)

The improvements have in each case chiefly consisted in the diminution of the size of the receptacles, and the consequent more frequent removal of their contents, this being accompanied by one or both of two sorts of nuisances—that arising from the offensive smell of the contents, which can only be partially prevented from escaping (by such contrivances as air-tight lids and so forth), and that caused by the too frequent visits of the scavengers—a nuisance thoroughly detested by every householder, whatever be his station in life. In neither of these systems is there any provision made for the removal of the liquid house refuse from slops, washing, cooking, and so forth, so that all these, and generally the chamber slops as well, have to be thrown down the sink and pass away into the sewers, thus necessitating the purification of the sewage in some way, and so leaving the great question unsettled. Indeed, the amount of purification which would accrue to the sewage from such a proportion of excremental matters and nothing else being kept out of it, is not nearly so great as is generally supposed, the other refuse matter that the sewers necessarily carry away from all towns being so great in amount that it is certain that, even if all the excremental matters could be kept away from the sewage, it would not be sufficiently pure to be allowed to empty itself into a river, and the necessity of purifying it would arise as much as ever. (See pp. 177, 178.)

Nocturnal visits.

Slops go into sewers.

Sewage must be purified.

CHAPTER IV

THE DRY-CLOSET SYSTEMS

Introductory.

WE have now to consider the two methods which have arisen more or less directly out of the incompleteness of the two foregoing ones, and which are the only ones that we can look upon as in any way affording something approaching to a solution of the question of excremental removal. The first of these, the so-called *dry-closet system*, has for its object the separation of the excremental matters *in toto* from the sewage, and the removal of a great part of them at any rate in a dry and inoffensive condition. The best form of this system, according to its originator, professes also in an indirect sort of manner to treat the other house refuse, liquid and solid; how far it is possible that it should *practically* achieve these results we shall presently see. The other is the *water-closet system*, by which the whole of the excremental matters, solid and liquid, together with all the liquid house refuse, is washed into the sewers, carried at once away from the vicinity of houses by the unaided force of gravity, and either, as has been hitherto the case, allowed to fall into a watercourse or into the sea, or utilised as manure by one of the processes that we shall hereafter describe.

ASH CLOSET.

The dry closet which approaches nearest to the best form of midden closet is the one in which ash is used as the deodoriser. This is described in a paper read before the Manchester and Salford Sanitary Association by Mr. Morell, of which an extract is given by the Rivers Pollution Commissioners, 1868 (*First Report*, vol. ii. p. 309). Each closet is provided with an ash-sifter, which is brought into motion by the opening of the door, the fine ash falling through into a storing measurer, fixed in the back wall. The seat of the closet is covered by a lid, which, when opened or shut, measures out into the excrement receptacle (an easily movable water-tight vessel) a quantity of ash sufficient to deodorise its contents. The cinders which do not pass through the sifter are of course used again as fuel. It is stated that whenever there is not sufficient ash-dust to be had, as perhaps may sometimes be the case in summer, "it is easy to supplement it by throwing on to the screener some fine street sweepings." For stories above the ground floor it is proposed to have a wide tube brought down to or below the ground floor, and opening into a receptacle placed there, which might be removed when full, or as occasion required. "A circular vessel, 2 feet deep and 1 foot 9 inches in diameter, will contain the ash and excrement refuse from one house with five occupants for twenty days. Removal once a week, or once each fortnight, for such a house, will therefore be sufficiently frequent." Mr. Taylor has patented a dry closet of much the same kind as the above, but in which the urine is not allowed to remain with the soil and ashes, but escapes from the soil-pan

Mechanism.

Street sweepings utilised.

Plan for stories above ground floor.

Separation of urine.

into a special receptacle at once, before the ashes are thrown upon the soil by the shutting of the lid of the closet. The advantages claimed for this method are, that the material required, ashes, is always on the premises, and would have to be removed in any case; that the apparatus is strong and not complicated, and its working easy; that the excremental matters are completely deodorised and rendered inoffensive; and that the mixture produced is very valuable as an agricultural manure, "selling readily for £8 a ton."

Ashes always at hand.

A very simple and effective form of dry closet is the Carbon Disinfecting and Deodorising Closet, of Messrs. Weare and Co., which is in use in some parts of Liverpool. Immediately under the seat is a perforated earthenware pan, and below this a movable box containing a perforated iron bucket, the space around the pan and bucket being packed with ashes and fine wood charcoal; in the lid is placed a box containing some disinfecting powder, which is dusted on to the excrement by the shutting of the lid; the excess of water passes by a pipe into the drain.

Weare's Carbon Closet.

These plans are open to nearly the same objections as the dry-earth system (see p. 119, etc.), but have the advantage that ashes are always at hand.

CHARCOAL CLOSET.

Sea-weed charcoal.

A cheap charcoal obtained from sea-weed, and which is stated by Mr. Edward Stanford, the inventor of the process, to contain 63 per cent of carbon, 34 per cent of ash, and only 2·6 per cent of water, is applied to the excreta in the same way as dry earth in the earth system, and the same kind of closet with an automatic apparatus for supplying the charcoal is suitable as for the earth closet (see p. 86); or a box and scoop may be used. It is stated that only one-third the quantity of charcoal is required for deodorising the excreta as of dry earth: about $\frac{1}{2}$ lb. is calculated as necessary for each use of the closet, equal to $1\frac{1}{2}$ lb. of dry earth. On removal the mixed charcoal and excrement are recarbonised by burning, and may then be again used in the closet; the products of distillation from the recarbonisation process are condensed, and consist of ammoniacal liquor and tar. From the ammoniacal liquor sulphate of ammonia and acetate of potash are obtained. After several uses in the closet the charcoal, now called "cycle" or "X" charcoal by the inventor, becomes highly charged with potash and phosphates, and when mixed with the ammonia distilled from it forms a very valuable manure.

Quantity required in use.

"Cycle" or "X" charcoal.

Mr. Netten Radcliffe investigated the working of the charcoal system in several places in Glasgow and on the Clyde. We may quote the following from his Report, as showing the very complete deodorisation effected by sea-weed charcoal. (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874, p. 228.)

Messrs. T. and G. Thomson's ship yard, Clyde Bank, a privy of thirty-six seats opening into a common vault, and used by 2500 workers. The vault constitutes a chamber, entered by folding doors on the level of the ground, the closets forming a storey above approached by stairs. The rule appears to be not to attempt to empty the contents of the vault until they approach the ceiling. At the time of my visit the vault was being cleared, and half the contents had been removed, leaving a section of the undisturbed half extending from floor to ceiling. Notwithstanding this newly exposed surface of the still great mass, there was no offensive odour, except in one or two spots, where, from careless use of the closet, or an empty hopper, a portion of uncovered fresh excrement lay.

No offensive odour.

The charcoal has no disintegrating action on the excreta like dry earth, for Mr. Radcliffe saw a twelve-months' accumulation of mixed charcoal and excrement from different closets in Glasgow, the section of which showed the excrement retaining its form, and the paper unchanged; the whole mass as well as the section being quite odourless. This is explained if, as Mr. Stanford believes from experiments made by him, the charcoal acts not as an oxidising agent but merely as a dryer.

Charcoal acts as a dryer.

Mr. Radcliffe in his Report remarks:—

Charcoal a most effective deodoriser.

Its disinfecting or germicidal action unknown.

> The examination of the charcoal closets in Glasgow and the vicinity proves, as was to be anticipated, that charcoal properly applied acts as a most effective deodoriser of excrement, and that this action in receptacles kept dry persists for an indefinite period. The assumption, however, that the mixed excrement and charcoal may therefore be safely stored for many months in the vicinity of or within the precincts of dwellings, appears to me to be at least premature. We know too little yet of the modes in which excrement acts in the production of disease to justify such assumption, and we are not less ignorant of the action of charcoal upon the disease-producing qualities of excrement. . . . The possible changes in a mixed mass of excrement and charcoal, which may occur under various conditions of moisture and temperature, are as yet wholly unknown. (*Loc. cit.* p. 229.)

THE DRY-EARTH SYSTEM.

Earth brought to the excreta.

The principle of this system is, that earth is the natural deodoriser of excremental matters, and the plan by which it is proposed to make earth available for this purpose is precisely the reverse of the one upon which all the other systems depend. It proposes to bring a certain quantity of earth to the manure, while all the others take the manure in some form or another to be placed upon the earth; in other words, a sufficient quantity of dry earth is to be brought into every community where this system is at work, completely to deodorise and render inoffensive all the excremental matters of population. In the prospectus of Moule's Patent Earth Closet Company it is stated that this system "is founded on the fact of the deodorising power of earth, a *given quantity* of *dry* earth destroying all smell, and entirely preventing noxious vapours and other discomforts. The practical application of this power consists in a reservoir for containing *dry earth*, and in an apparatus for measuring and delivering the requisite quantity, so as to deal with every operation *in detail*. This apparatus can be applied to most existing closets." The first essential, then, in the working of this system is that the earth should be *dry*, and the second that it should be applied *in detail*, that is to say, that each particular stool must be covered at once with the requisite quantity of this dry earth. It is found in practice that 1½ lb. of dry earth (2½ lbs. would appear to be required in India) is sufficient to remove all smell from the stool when thrown over it, and the mass remains inoffensive for two or three months, or even more. It appears that a chemical action takes place in the intimate mixture of earth and excrement which results in the complete disintegration of the fæcal matters. After a time no excremental matter whatever can be detected in the mixture; everything disappears, even paper. After keeping and drying it may be used again many times with the same result, but it is not found that this repeated use is advantageous in an economical point of view. Less earth than the amount above specified is insufficient, more is useless. In a pamphlet by Messrs. Girdlestone, the engineers of the Earth Closet Company, it is stated:—

Essential conditions.

Action of earth.

May be used several times.

1. That any surface-earth and almost any clay will deodorise excrementitious matter, but that sand and chalk will not.

2. That such earth, if dried and sifted, has such power of absorption that it is capable of receiving both liquid and solid excreta, and

Kind of earth required.

of rendering their removal practicable without offence, and also without any loss in the value of the manure.

3. That a very small quantity of earth is required, and that the same portion of earth may be repeatedly used with the same effect.

Prevention of fermentation.

4. That the action of the earth on the excreta is immediate, all fermentation being prevented, the obnoxious agent being dealt with at once and in detail.

5. That while the earth absorbs the excreta, they in their turn possess a decomposing power, such that any extraneous matter deposited with them disappears in a short time.

6. That the absorption and deodorisation of the excreta result in preventing infection. (*The Dry-Earth System*, p. 4.)

Best kinds of earth.

In Dr. Buchanan's report (Twelfth Report of the Medical Officer of the Privy Council) on the working and applicability of this system, he states that dry clay and loamy surface-earth, but especially the brick earth of the drift formation, are the kinds best suited for the purpose, and that after a month or so the mixed mass of excrement and earth may be wetted and moderately heated without producing any smell.

The closet.

With regard to the particular closet or commode, it is of much the same kind as the one that has been described as the patent ash closet. A receptacle for the dried earth is placed at the back, and either by a handle (the "pull-up") or by the action of the seat itself (the "self-acting") the requisite amount of earth is allowed to fall from the hopper into the pit or vault so as to cover the excrement. It is plain that the earth-receiver may generally, at any rate in fixed closets, be carried up to a considerable height in the wall so as not to require replenishing for a long space of time. For upstairs closets it is proposed to con-

Shaft for upstairs closets.

struct a shaft inside or outside the house, down which the contents of the pail may be emptied, or the pail itself may be fixed and connected with an earthenware pipe which descends vertically into a vault beneath. The prices for commodes vary from £2, that of the single movable nursery commode (for children), to £7 : 5s., that of a more finished kind, on castors, with self-acting apparatus and fixed seat. If larger earth reservoirs are required, the cost is somewhat more. The tanks for the closets cost from 7s. 6d. to £1 : 5s. each, and the apparatus for placing in closets costs £1 : 15s. for the pull-up, and £2 for the self-acting (without the pails or tanks), while the apparatus for upstairs use, including the pail and pull-up mechanism, comes to £4. Cost of apparatus.

The commodes are made so that they can be easily moved and placed in any convenient situation in-doors or out-of-doors: they are especially intended for use in bedrooms, hospital wards, and so forth, and it is claimed for them that they—like the closets—entirely prevent all disagreeable odour when properly supplied with dry earth. It is stated that it is necessary "to cast one service of earth into the pail when first placed in the commode." It is essential that the earth be both dried and sifted. For large communities it would be advisable that these operations should be carried on at one spot and on an extensive scale; but for country houses, where each household would probably prepare its own earth, a small portable dryer may be obtained for from £1 : 10s. to £2, and a dustless sifter for earth and cinders for £1. As a general rule it would be found that the sifting might be performed by means of an ordinary riddle or sieve. It need hardly be stated that it is absolutely necessary for the proper working of these closets that no slops should be thrown into them. If even the contents of the bedroom utensils be poured down them it would be necessary to supply them with a considerably larger quantity of earth. In public places urinals can Commodes. Drying and sifting of earth. No slops to be thrown in. Urinals.

easily be constructed acting on this principle, and are certainly, when properly supplied with earth by hand labour, almost entirely devoid of any offence. The system is now at work in several large institutions, and it has undoubtedly been found, when properly managed, to work well. The Criminal Lunatic Asylum at Broadmoor is entirely supplied with earth closets, the water-closets with which it was originally supplied having been done away with because it was found that they were "a constant source of expense and annoyance," this being caused by the fact that the water supply apparatus was not very good, and that the closets were not properly ventilated. Now a mixture of sifted peaty earth and ashes is used, and the earth and excrement fall into a galvanised iron pail provided with wheels. The slops are still passed through the drains originally laid down by Mr. Menzies, as also is the urine from the men's urinals, and this mixed liquid is used to irrigate "some grass lands in the adjacent valleys."* It is stated that the only fuel required for drying the earth in the most efficient manner is provided by the cinders which are sifted from the ashes of the establishment, the fine ash being mixed with the dry earth (which is dried in a kiln built for the purpose). It is also stated that in this establishment there is a saving of nearly half the amount of the water originally used. It will be noticed that this asylum affords an instance of a place where the water-closet and irrigation system has been changed for the earth-closet system, plus the utilisation of liquid refuse by means of irrigation as before.†

Examples of the working of the system.

Slops and urine still go in drains.

Saving of water.

Irrigation.

* The Dry Earth System, p. 7. (Messrs. Girdlestone.)

† Since 1880 earth closets have been discontinued, and water-closets re-established throughout the Asylum.

In the Dorset County School "the ordinary system previously employed had resulted in trouble and annoyance perpetually recurring" (Messrs. Girdlestone). We find from Dr. Buchanan's report that the whole of the day urine is dealt with as well as the stools, but that the night urine goes with the slops, a sufficient proof of the impracticability of the plan which has been proposed for separating the urine from the other slops. At this school the system is carried out in the following manner:—There is a water-tight vault with two closets at each end of it, the urinals being placed between. The dry earth is stored in a shed close at hand, and with it the hoppers of the closets are filled as often as required, and the urinals are supplied four times a day. A ton a week is required, or 4 lbs. a day to each boy. The contents of the vault are removed without any smell, except on an occasion when earth had been supplied in insufficient quantity. It is stated that the agricultural value of the earth which has been twice through the closet is from £2 to £3 a ton, or 15s. a year for each boy. (We do not see how this is possible, the value of the total excreta being only 10s. a head at most.) The closets caused no offensive smell, and the diarrhœa, which had been epidemic in the school, has ceased since their construction. A "low fever" which existed in parts of the town around the school in 1866 and 1867 did not show itself in this establishment at all. The whole cost of the repairs of these closets in four years is stated to be less than 10s., while that of the water-closets was more than £3 a year. From the same report we find that at the Dorset County Jail these closets have been used for three years for the whole dejecta, both night

Day urine dealt with.

Quantity of earth.

Value of the manure.

Sanitary result good.

and day. About 3 lbs. of earth a head are used daily; this is not enough. The manure is kept in a heap in the shed; when turned over for drying it is found to cause a bad smell. It fetches about £1 a ton, or 10s. a year for each prisoner. A saving to the extent of £15 a year in plumbers' bills is said to have taken place. The health of the prisoners has not been affected, having been good under both systems. At Lancaster Jail the pail system was found always to be offensive, notwithstanding the provision of water-tight lids for the receptacles. Earth closets are now substituted for the pail closets, and are supplied with earth by hand, each prisoner throwing it into his closet with a scoop. Dr. Buchanan saw a heap of compost in the shed in the yard, and found no smell in the shed, but a handful of the mixture had a urinous odour. The slop water and the contents of the pails that are left are thrown into the sewers. At the Grammar School in Lancaster these closets answer very well, as also at the national schools: the only one found in an offensive condition was one of the girls' closets, into which some large stones had been thrown by some workmen, and to which earth was not supplied pending the removal of the stones. It was stated here that the trough water-closet was found to be very offensive. At St. Mary's College, Oscott, near Birmingham; at the Manx Lunatic Asylum, Isle of Man; at Reading Union Workhouse, and at other workhouses and factories, the system has been successfully applied.

Results at Dorset Jail.

Pail system offensive.

Compost inoffensive.

Failure of trough water-closet.

At Wimbledon camp, since 1868, this system has been annually in operation. In 1866 and 1867 the excrement was removed by water through drains into a brook, causing of course "serious nuisance in the neigh-

Wimbledon camp.

bourhood." In 1867 earth closets were tried on a small scale, and they were found to succeed so well, that in 1868 they were established throughout the camp.

The plan adopted at Wimbledon is a very simple one. Rows of closets made of deal boards are placed back to back, with a passage between the rows, to which access is only attainable by the attendant. Under each row a long pit is dug in the ground ($4\frac{1}{2}$ feet deep by 5 feet wide), into which the excrement falls. Each closet has an apparatus which is worked by the weight of the person on the seat, and which causes $1\frac{1}{2}$ lb. of dry earth to fall from the receptacle on to the excrement. The urinals are also placed over the pits, and are supplied with dry earth by hand labour. Each urinal requires about 180 lbs. of earth in a day. Before the meeting 120 tons of earth were dried and stored, and it was found that 140 were required. The hoppers of the closets are filled every morning, and refilled as often as required by an attendant. It is estimated that the public closets were used once a day by 3000 persons, and the public urinals more than 10,000 times in the day: five ounces being the average weight of a stool, and six fluid ounces the average quantity of urine at each micturition, it follows that "a total of nearly 1000 lbs. of solid and over 3000 pints of fluid excrement" were thus disposed of daily. (*Twelfth Report, M. O. P. C.*, p. 90.)

Arrangement.

Quantity of earth.

Amount of excreta disposed of.

In the *Times* for 24th July of that year it was stated that "hitherto chloride of lime, flushing, and various other expedients have been resorted to, and have worked more or less successfully, but always with drawbacks of a too obvious character," but that, notwithstanding the increased numbers in the camp, and

Superiority over other systems.

the excessive heat, the earth closet had succeeded so perfectly, that there was "absolutely no annoyance of any kind."

The *Lancet* also bears testimony to the great success of these closets at Wimbledon, and points out that it "follows, as a matter of course, that they must be in every way suitable for the exigencies of rural districts."

The number of closets in the camp is stated to have been 108, and of urinals 46; the number of volunteers was 2300, and the number of visitors 34,792. It is plain that the system was here subjected to a very severe test, especially when the excessive heat of the weather is taken into account.

Unfavourable opinions.

It must, however, be observed that the opinion that the earth closets at Wimbledon in the year 1868 were in every way a success, although maintained by Captain Drake and Surgeon-Major Wyatt, was not shared by every one who saw their working throughout the meeting. Dr. George Johnson pointed out that there was probably some close relationship between the earth closet system and the great prevalence of diarrhœa in the camp; and though the cause of this diarrhœa has been to a certain extent explained by the excessive heat of the weather (diarrhœa having also been very prevalent in London at the same time) and the too great use of imprudent drinks by the men, yet Dr. Reed maintains that the earth closets had a good deal to do with it. He says: "The trial of the dry earth closets in 1867 proves that when they are used by *a few persons only* they act very well, and will answer in isolated houses where earth can be procured *in such quantities as actually to smother the excreta;* but the trial in 1868 proves that in camps, and if not in large towns, they (in my opinion) are useless and highly dangerous to health." In the letter just quoted, which appeared in the *Lancet* of 17th April 1869, Dr. Reed states, with regard to the earth pits, that "by the time the camp was nearly over these cess-pits became cesspools full of nothing but excreta, urine and mud. . . . Any one who had to visit these places at Wimbledon in 1868 can testify to the fact whether even 'deodorisation' was perfect or not. . . . The excreta and so forth were not 'deodorised' or 'disinfected' and 'rendered innocuous' in the Wimbledon camp of 1868." He agrees with Dr. Johnson that the prevalence of diarrhœa in the camp was due to the "stench" given out by the closets: adding that the supply of earth was too limited. "Frequently by ten o'clock A.M. many boxes were empty, and were never refilled all day. The working of the apparatus was uncertain, for frequently the earth would not pass through, either because it was too damp or the place was choked up." On Captain Drake's denying these charges, and stating that the earth system was gradually introduced and worked on the whole successfully, acknowledging at the same time that there were some "offensive closets," and that the "self-acting apparatus in the urinals was unsatisfactory and was purposely put out of gear," and in answer to a letter from Messrs. Girdlestone, the engineers of the Earth Closet Company, quoting the opinion of Surgeon-Major Wyatt, who expressed his "cordial approval of Moule's system of earth closets, the merits of which have been severely tested," Dr. Reed pointed out that Captain Drake admitted the truth of the bulk of his accusations, and maintained that the reason why some latrines had to be emptied

Dangerous in towns.

Imperfect deodorisation.

Earth not well supplied.

Charges partly acknowledged.

during the meeting was, as he had stated, that they became filled with urine, excreta and mud.

In fact, in an article in the *Lancet* of 3d July 1869, Surgeon-Major Wyatt, while pointing out the difficulties of attempting to work any other system than this successfully at Wimbledon, acknowledges that in 1868 the arrangements for carrying out the earth closet system "were not quite so perfect occasionally as could be wished," and that the closets were not always deprived by the earth of their odour on account of the excessive use of them, advising that we should "try again under more favourable circumstances and better surveillance." He also suggests that the earth should be mixed with about one-fourth of its weight of freshly burned lime, and that Macdougall's powder should be employed for the use of the urinals.

Improvements suggested.

Success in 1869.

With regard to the meeting of 1869, Surgeon-Major Wyatt says (*Lancet*, 24th July): "During this meeting, a better surveillance of the closets has been insisted on, and they have been used to an enormous extent by the vast concourse of people assembled, but I have heard of no complaint of any want of deodorisation;" and Captain Drake describes a few points to which attention should be directed in introducing the system into barracks or permanent camps, especially insisting on the quality of the earth, which "should be a clayey loam, friable and thoroughly dried. No soil must be used which contains vegetable matter;" and observing that the urinals should be separated from the latrines, and supplied with earth by hand twice a day, "no self-acting apparatus being found to answer."

Supply of earth.

The pits filled during the meeting of 1868 were emptied in the summer of 1869, and a bad smell was produced during the operation. This is stated to have been caused by the fact that the earth was not of a good kind, and that the quantity was too small. In 1869 the pits were emptied directly after the meeting, and very little smell was noticed; the quantity of manure produced was 117 cubic yards. In 1870 the closets undoubtedly acted well on the whole, and diarrhœa was prevalent to no great extent. On one occasion, however, we remarked that the closets were very offensive, exceedingly so, probably from not having been properly supplied with earth; and we find from the *British Medical Journal* of 6th August that "throughout the meeting there were occasional evidences of Moule's earth system breaking down; but these were, we believe, due in a great measure to the defective earth supplied for use."

Bad smell on emptying the pits.

Occasional failures in 1870.

From a table compiled by Staff-Surgeon Owen, given in Mr. Netten Radcliffe's Report (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874, pp. 225, 226), we find that since the year 1868, when with a strength of 2159 in the volunteer camp at Wimbledon, there were 309 cases of diarrhœa, until the year 1874, the largest number of cases at any meeting has been 59, in the year 1869; whilst in 1874, with a strength of over 3000 men, there were only 3 cases. The earth closets were in use during the whole of this period. These figures tend to confirm the conclusion arrived at by Dr. Buchanan, that the prevalence of diarrhœa in 1869 was not attributable to the earth closets, but was "part of a general prevalence common to the camp, and the whole of the metropolis." Mr. Radcliffe inspected the earth closets in 1874 on the eleventh day of the meeting, and reported them to be working admirably.

Diarrhœa at Wimbledon camp.

Earth closets working admirably.

Conclusions from Wimbledon experience.

On the whole, then, we may conclude that this system has at Wimbledon worked well whenever the requisite care and attention have been given to it, but that, whether from mistakes made "as to the detail of the number of latrines in different places causing some closets to be overcrowded," as Captain Drake stated, or from the supply of earth being insufficient or insufficiently dried, it has not always been found practicable to keep the closets in perfect working order. Nevertheless the system is still adopted at Wimbledon Camp, and on the whole works well.

THE EARTH CLOSET SYSTEM IN INDIA.

Success in Bengal.

The general conclusion of the reports of the Sanitary Commission for the Bengal Presidency, and of the Governments of Fort St. George and Bombay, are to the effect that the dry earth system is a great improvement on the former state of things, and that it has been found to be a "public benefit of very great value."

Dr. Mouat, the Inspector-General of Jails, writes :

> It is, in my humble judgment, impossible to over-estimate the benefits that will result from the labours of the Rev. Mr. Moule in this important branch of hygiene. It has already, in the infancy of its introduction in Bengal, worked wonders, and I have little doubt that its economic advantage will hereafter be as great as its immediate in-influence in promoting the comfort and improving the health of all public institutions in which it is properly used. (See *Report*, No. 126, dated 18th April, 1867.)

Suitable for jails.

The system is at work in the jails of the Punjaub, of Oude, of the Mysore and Coorg provinces, etc., and the Commissioners all report most favourably of it.

From the proceedings of the Government of Bombay it would appear that the introduction of the earth closets into hospitals and jails has been often attended with success, especially "in some hitherto notoriously unhealthy jails;" but we find a great many reports of failure from various causes: "Earth could not be got except from a great distance;" "carbolic acid powder is used, and is preferred;" "failed during the monsoon;" "tried for two months, but discontinued, as the men could not be prevented from using water." Nevertheless, there is no doubt that the great majority of the reports are very favourable to it. Some causes of failure.

It would appear that the dry earth principle has been for a considerable number of years in use in India, it having been "employed in the Punjaub, introduced by Sir Henry Lawrence many years before it was perfected as a system by Mr. Moule." "Although it had been used as far back as 1854 in the Poona jail, Dr. Ogilvie was the first in this Presidency to employ it systematically, but not by any means in so complete a form as it is now used under Mr. Moule's system." (No. 1594, dated 26th April 1867.) First introduced by Sir Henry Lawrence.

Sir Henry Lawrence's plan was a very simple and effective one: the privy was merely the space between two low walls; dry earth and cook-room ashes to the depth of four or five inches were spread in it, and also in front of it to absorb urine; while a heap of earth with a wooden trowel was provided opposite each seat, and every prisoner was required, under pain of severe punishment for neglect of this duty, to throw some of the earth into the privy immediately after using it; the trenches were to be cleaned out "twice, thrice, or oftener in the day," and fresh earth supplied; while during the rains, matting coverings were to be provided. Simple plan.

The Madras Reports have not been so favourable Madras Reports.

to the system on the whole; they are very important, as they enter in the minutest manner into practical details. In examining carefully these Madras Reports (1867-8-9), we are at once struck with the great practical difficulty that there appears to have been in carrying out this system, even where so much hand labour can be got cheaply, and with the conviction of every one who has had anything to do with it that the system inevitably fails where the most efficient supervision is not continually given to it. We find such statements as the following:—

How far successful.

That wherever large numbers of persons *under control* are congregated, Mr. Moule's system of conservancy has been entirely successful, and that it is, so far, a great public benefit.

As in many stations in India a good system of drainage and water supply are both deficient, Mr. Moule's system of dry earth sewage is the best means available for our barracks, hospitals, jails, and other public institutions. (No. 125, 22d May, 1867, pars. 9, 12.)

Great care and constant attention are required in adapting all the parts of the process to each other: mechanical difficulties have been experienced in the use of hoppers for throwing in the earth; scoops for throwing in the earth after using the latrine are imperfectly applied; native servants have had to be appointed to this duty. (*Report on Sanitary Improvements in India*, 1869, p. 209.)

Weight of earth necessary.

It is insisted in these Reports that $2\frac{1}{2}$ lbs. of dry earth is the least quantity that can be accepted "as the weight of earth necessary to deodorise and maintain in a state of inoffensiveness the solid and fluid dejecta of a healthy adult, as ordinarily passed into a privy-pan or tub of moderate sectional area;" but this, it must be observed, does not include any urine other than such as is passed during the use of the closet. From Surgeon-Major Ross's experiments it appears that $2\frac{1}{4}$ lbs. of earth are required for each use of the urinal, and that provision must be allowed for three such uses during the twenty-four hours. The aggregate amount of urine passed being thirty fluid

Amount of urine.

ounces, or $1\frac{1}{2}$ lb. (pounds and pints of urine are, practically speaking, convertible terms), it follows that 36 lbs. of earth are required for each gallon of urine, and this is certainly the least estimate. From this it appears, that to deodorise the urine of 1000 men no less than 1099 tons of earth would be required per annum. It is scarcely wonderful that "in the urinals the Commission think that the difficulty, owing to the enormous quantity of earth to be brought and removed, 'is practically insuperable;'" and that in their suggestions they state that "pans designed to separate the solid and fluid feculence should be adopted if possible;" Dr. Ross estimates the total quantity of earth required to deodorise the whole excreta of an adult at $9\frac{3}{4}$ lbs., of which 3 lbs. will be required in the latrines, and $6\frac{3}{4}$ lbs. in the urinals. "This raises the amount required to be supplied for 1000 men to something like 1588 tons per annum, while the mixed earth and ordure to be removed will amount to 1995, or say 2000 tons! This is undoubtedly an enormous mass of soiled earth to transport to the place of deposit." (*Proc. of San. Commissioner for Madras*, 1868.)

Impracticable for urinals.

Enormous amount of earth.

After pointing out the necessity of dryness, pulverisation, and immediate application of the earth, and insisting that it is also necessary that no water be used in or about the latrines, and that "any incidental dripping of fluids must be covered and absorbed by dry earth," the qualities of various kinds of earth are also discussed. Dr. Blakelock has shown that "7 lbs. of clay have the same deodorising power as 17 lbs. of the ordinary sandy loam procurable at Madras." The order of eligibility of various soils is stated to be the following:—(1) rich garden mould; (2) peaty soils; (3) black cotton soils; (4) clays; (5) stiff clayey loams;

Value of different sorts of earth.

(6) red ferruginous loams; (7) sandy loams; (8) sands.

Pug-mills.

Contrivances called "pug-mills" have been established for mixing thoroughly the earth and excrement. Opinions seem to differ very greatly as to the efficiency of the working of these mills, but Dr. Ranking concludes that "efficient supervision, in fact, ensures all that is contemplated by the use of the mill, while neglect entails failure and needless expenditure," (par. 61).

Macdougall's powder for the urine

A considerable amount of evidence was brought forward to show that Macdougall's disinfecting powder, which costs £10 a ton, may be used with advantage for the deodorisation of the urine, the dry earth being only supplied to the latrines. "Dr. Stewart Clarke states that six per cent is sufficient to deodorise and maintain in a state of freedom from ill odour the solid and fluid excreta of latrines and urinals;" and he shows, with regard to urine alone, the total annual quantity for 1000 men, plus six per cent for disinfecting fluid, comes to 580,350 lbs.; whereas in the earth process the amount to be removed would be "no less than 3,011,250 lbs., or 1344 tons!" (*Loc. cit.* par. 69.)

Sanitary benefits from earth closets.

Dr. Ranking, towards the end of his Report, states that "there is abundant evidence to prove that the introduction of the dry earth system has effected a marked change in the sanitary condition of barrack and hospital privies and urinaries, and that it has exerted a most beneficial influence upon the health of the troops." When we put by the side of this sentence the following statement by the Inspector-General of Prisons in the Bombay Presidency—"this simple

Former system.

and inoffensive system has entirely superseded that of noxious drains and cesspits formerly in vogue"—

we are able to understand at once that the earth closet system carefully carried out has been an undoubted improvement upon the former state of things. Even in these earlier reports it is pointed out that "the objection to the system is the great cost of furnishing earth for daily use, and of its removal. In these respects water conservancy, by which human excreta can be removed in suspension by public sewers, will, wherever water supply is available, be found more economical." And again: "As regards the ultimate use of human excreta as manure, it is probable that when thus diluted and applied to the soil, this form of manure has more fertilising properties than the excreta mixed with dry earth and known as *poudrette*." But from a memorandum by the Army Sanitary Commission (No. 8) in the Report on Sanitary Improvements (1869), we find that the practical difficulties in the working of the system, instead of decreasing with experience, have, on the contrary, increased to such an extent as to oblige the authorities to look for some other method for the disposal of their refuse. The Commission point out that it is insufficient "to remove only one class or cause of impurities and to leave the others; and no sanitary proceeding which does not deal effectually with all of them can be considered as sufficient for health." (*Loc. cit.* p. 208.)

Water carriage more economical.

Liquid manure better than solid.

Difficulties increase.

The following sources of impurity require to be continuously removed from inhabited buildings in India, as elsewhere:—(*a*) solid kitchen refuse, including debris of food; (*b*) rain water, which would, if left in the subsoil, tend to generate malaria; (*c*) all the water brought into the station, except that which accidentally evaporates. This water is used for drinking, cooking, washing, baths, and lavatories. The amount cannot be taken at less than 12 gallons per head for every healthy man, woman, and child, including servants; from 30 to 35 gallons per head for every sick man per day, exclusive of water for horses. . . . Practically this water in all climates, but especially in India, becomes, if not safely disposed of, an inevitable source of disease

Total refuse.

Foul water.

and ill health. It contains a large amount of putrescible matter, and, if urine were mixed with it, it would become so noxious that it would matter very little whether or not the contents of latrines were added to this other sewage; (*d*) the matter from latrines, including solid and fluid excreta, at about one pound per man per day, or, in round numbers, half a ton per day per thousand men.

Excreta.

They state that the solid debris being removed by hand or cart labour, the refuse water must "either be passed into cess-pits, or it must be carried away, or it must be allowed to find an outlet where it can by surface drains—probably into the subsoil." That the rainfall must be removed in India "by improving the surface, and by impervious surface-drains," while the subsoil must be freed from excess of water by subsoil drains. The latrine matter, with which alone the dry earth system proposes to deal, "is to the fluid refuse of barracks, hospitals, cook-houses, and so forth, as 1 to 190; that is, for every pound of human excreta removed under the dry earth system, there are in every well-regulated establishment about 190 of fluid refuse which must be otherwise disposed of." The earth system, then, "deals only with one part out of 191 of the total injurious barrack and hospital refuse, while it makes no provision for the removal of surface or subsoil water." After pointing out the various practical difficulties which have already been noticed, and alluding to Dr. Ranking's suggestion to deal with the urine separately by Macdougall's disinfecting powder, they remark on the practice of burying the mixture of earth and excrement, stating that it "must result in fouling large areas of ground;" for that, "even after careful mixture of excreta with earth, the mass when buried gives out offensive vapours in rainy or damp weather" (pars. 4-15).

Earth closet disposes of only one part in 191 of the total refuse.

The compost becomes foul when damp.

It further appears that when a small quantity of the deodorised and buried excreta is taken up and diffused in water, the resulting fluid is found under the microscope to teem with vibriones and other forms of organic life, the very forms which some writers have included among the causes of Asiatic cholera. Without laying undue stress on this fact, it still may be taken as showing that, in India, the earth process and subsequent burial are inadequate for the requirements of health, at least in the case of large fixed populations, and that if this process is to be continued for such populations, it may be modified and brought more in accordance with natural laws (pars. 16, 17). Develops vibriones in water.

Here we may remark that the burial of this manure in pits is no part of the earth closet system, and that sanitary evils resulting from this practice are not to be put down to the blame of that system, except inasmuch as it has been found impracticable to sell the manure at a price which would pay for its carriage to a sufficient distance. Burial of it in pits a mistake.

The suggestion with regard to cholera reminds us of Pettenkofer's views, and, coming as it does independently of them, must be taken for what it is worth when viewed in the light of his objections to the dry earth system. The application of deodorised matters as manures is referred to in these terms:—

If the deodorised latrine matter were used for agricultural purposes, it must be borne in mind that all manure must be in solution before it can be taken up by plants, and if it must be in solution it may as well be conveyed in water. Now, conveyance by water in England costs only a tenth part of conveyance by cart. Foul water already containing manure in solution exists at the stations and is not removed by the dry earth system, but it is absolutely necessary that this foul water, derived from the water supply carried into stations, should be removed from them. By far the cheapest way of doing this is by drains, and, if there be drains for foul water, there is no reason why the latrine refuse should not be carried away in the same drains. . . . The first cost of trough latrines or soil-pans may be taken at £1 sterling for every ten men. . . . There must be foul-water drains unless the foul water is carted out of the station. To have two systems of cleansing stations, a foul-water system and a dry-earth system, would simply be paying double where one payment would answer; or if all the excreta, solid and liquid, are to be carted away, this must be done at a cost ten times greater than that which would be necessary if all the excreta were removed by drains. . . . The removal of latrine matter is simply an

Manure must be in solution.

Drains necessary.

Why two systems?

incident in the drainage of a station, and in draining a station we have only to consider the population and the amount of water supply brought into the station and fouled by domestic use. The real question is how this foul water can be most easily and cheaply removed. It is necessary to enunciate this principle broadly, because the amount of nuisance from imperfect latrines in such a climate as India has naturally drawn the attention of medical and other officers to the necessity for abating this nuisance, to the possible underrating of sources of disease from the foul water of stations of equal if not of greater importance. (*Loc. cit.* pars. 22, 23, 24, 26.)

Removal of foul water the chief question.

It therefore follows that the foul water must either be carried away in drains, or be carted away at stated periods (becoming putrid in the interval), at ten times the cost. The water latrines could be emptied into the drains, a proceeding involving no additional expense, but doing away with the whole cost of the earth closet system.

Too expensive to cart it.

Whether the dry earth system be used or not for latrines and urinals, the health of stations will be only partially improved, unless provision be made for removing away from stations all the foul refuse water as well as the malaria-producing subsoil water of the station (par. 25).

Subsoil water.

The Commissioners then discuss some of the results that have been attained by the irrigation system, and "suggest whether some one Indian station might not be improved on similar principles, and the sewage rendered available for supplying troops and horses with farm produce" (par. 50), and they conclude their report as follows (par. 52):—

Irrigation proposed.

It will be seen that the fundamental point in the question is the removal out of the station of all water brought into it for domestic use. The cheapest way of doing this is by drains laid to an outlet; and if drains be provided, there is no reason why the latrines should not be connected with them. But if from local circumstances it be impracticable to remove refuse water by drains, then the other alternative of collecting it carefully and carrying it away will have to be adopted, and in this case the latrine matter might be separately dealt with for agriculture.

Latrines to communicate with drains.

It should be added that "there is, however, scarcely a plan which has come before the Committee showing a fall in the ground which would render natural drainage impossible." It is difficult to suppose that a system that has been attended with such practical disadvantages (even under the advantageous conditions presented by the systematic management of barracks and prisons) that the question of abandoning it is already being considered, is ever likely to be turned to any account for the removal of the solid excretal matters of the populations of large towns.

Drainage by gravitation almost always practicable.

Difficulties much greater with towns.

The Indian Report* for 1869-1870 goes to show that the dry earth system may be successfully applied to scattered houses, barracks, etc., but that it is unsuitable for towns.

The system had not been authoritatively introduced, but more or less efficiently carried out, was the recognised system adopted in barracks, hospitals, and lines of native regiments. It is, in fact, the only system possible in the large majority of stations in the Madras Presidency, where the water supply is scanty and precarious. Sewerage by water-carriage may be applied in some of the new stations, where the barracks and subsidiary buildings are located within a moderate area, but could not be applied to officers' homes, and cantonments at large, scattered over an area of many square miles of ground. (*Loc. cit.* p. 132.)

Suitable where water supply is scanty.

The results reported are considered to prove the superiority of the system in regimental latrines over any other that has been tried. (*Ib.* p. 72.)

On the other hand, Miss Nightingale, in her remarks on the Progress Reports, says (p. 43) :—

In the documents received here no reference is to be found to the surface or subsoil drainage of stations ; no reference to sewering of buildings. Dry earth conservancy is apparently the only thing attended to, although is it not simply a matter of common knowledge that the dry earth system makes little difference in the amount of dangerous impurity contained in the fluid sewage of a station or town ?

while the Army Sanitary Commission speak, if possible, still more strongly in condemnation of this

* Report on Measures Adopted for Sanitary Improvements in India, from June 1869 to June 1870.

system as applied either to towns or stations. In their replies to Dr. Cuningham, the Sanitary Commissioner with the Government of India, they say, after mentioning the results of the experiments conducted by the Rivers Pollution Commissioners (p. 206)—

Does not provide for refuse water.

It follows, that to trust to dry earth conservancy for improving the health of towns, while ordinary station or town drainage is permitted to soak away in cesspits or on the surface, is simply to poison the subsoil with sewer-water, which, if collected and conveyed in drain-pipes, would become a valuable manure. The question may now be considered as settled by scientific investigation, that the sewage of inhabited buildings should be treated as a single element, whether as regards health or agriculture, and also that to divide this sewage into two parts, and to remove the parts separately, is, as we have stated elsewhere, to pay double where one payment would answer every purpose.

And not only so, but (*loc. cit.* p. 38),

Unsuitable for large cities.

From the quantity of earth required, and the practical difficulties attending its cartage, distribution, removal, etc., the Commission considered that the dry earth system could not be generally introduced into a large city like Bombay.

Dr. Rolleston, in his papers published in the *Lancet* (7th and 14th January 1871), has shown clearly enough that enteric or typhoid fever is one of the jail fevers in India; but Dr. Buchanan thinks (*Lancet*, 4th February 1871), that so many fevers are included under this term, that no conclusion can be drawn as to the effect of the dry earth system on the prevalence of enteric fever. Future careful observations will no doubt settle this point, but in the meantime we think that Dr. Rolleston puts the case very fairly when he says—

I have upon other occasions pointed out times and places in which a dry earth system of conservancy may have claims upon our favourable consideration; those times, I have always held, are not times of epidemics; those places do not lie within the *enceinte* of large towns. —(*Lancet*, 14th January 1871.)

THE EARTH CLOSET IN VILLAGES AND TOWNS.

With regard to the applicability of this system to villages, it is stated in a published letter, that "in the villages of Halton, Buckland, Western Turville, and Ashton-on-Clinton, on Baron Rothschild's estate in Buckinghamshire, with a population of about 800 persons, the system has been in use for eighteen months. The overflowing and fever-breeding cess-pools, ditches, and privies have been cleared, and not a foul smell can anywhere now be found." Its working at Halton is described in Dr. Buchanan's Report, which we have so often quoted: it has been there in use for three and a half years, the thirty-three houses of Halton being all supplied with earth closets, which are detached from the house in all but two cases. The earth used is a loamy garden mould, well dried; it is used twice. There is an opening at the back of the closets for the supply of earth and for the removal of the manure from the pit. A self-acting apparatus is supplied which acts by the weight of the sitter. One hundredweight of earth a week, on the average, is required for each closet. A very slight smell is said to be caused during the drying process, but it is so trifling that it offends no one.

Improvements at Halton.

Arrangements.

Ashton-on-Clinton, a village two miles off and with twenty-two closets, is managed by the same scavenger as Halton, with one horse and cart, and the occasional services of a boy. It is estimated that 600 people *together* could be managed with the same staff and at the same cost as the 300 in these two villages. The cost was as follows:—the drying sheds and kiln cost £150; the weekly cost was 25s., namely, 15s. for the man's wages and 10s. for firing, occasional cost of

Cost.

horse and boy, and all other incidental expenses. The earth passed *once* through the closets, was stated to have a minimum value of £3 a ton; but, on the supposition that earth passed *three times* through them has this value, the gross annual return would be £130, or under 10s. a head. (*N.B.* This is above the possible value unless all the urine is retained.) A half of this would meet the current expenses, and the other half would remain for repairs, for repaying the original outlay, and for profit.

Value.

In the instance in which the closets are under the same roof with the house, "the occupiers, not liking them so placed, had only used them occasionally when there was sickness in the house; for ordinary use they had a garden privy with cesspool, the only one left in the village; it was a typical, old-fashioned privy, and gave the only decided stink met with throughout Halton."

Earth closets not liked in the house.

These villages are both well supplied with water and sewerage arrangements, and each cottage has a piece of ground attached to it; fever and diarrhœa are wholly absent from them, but this was the case for years before the introduction of the earth closets.

In Lancaster, earth closets have been introduced by Mr. Garnett into some of the poorer houses—450 in number, and inhabited by about 2250 persons, or one-seventh of the population of the town. The pits of the latrines are emptied once a month; the scavengers visit each latrine once a day, and put in earth for twenty-four hours' use, allowing about a pound for each use of the closet. No slops are allowed to be put in, and the urine is collected in large vessels and removed by men, as it is found to be less expensive to remove it than to bring sufficient earth for it.

Closets visited once a day.

Some of urine collected separately.

Some closets are, however, used for the whole of the excrement and urine of the population. Fourteen tons of earth are required for the 450 houses. The ashes were first mixed with it, but this year (1870) nothing but earth is used. There was no odour *except where the orders about slops had been disobeyed.* They were altogether found to work better than the water-closets in similar parts of the town, which get choked up and become offensive. The soil from the closets is here not dried again for use, but carted away crude up to the top of a neighbouring hill, mixed with blood, offal, and straw—from the shambles—street sweepings, and so forth, and spread in long heaps, with a tramway along the top of each heap; the urine which has been collected from the houses is added, by means of water-carts which run along the tramways. In the summer it is at once absorbed, but in the winter the surface is wet, and the heap is found to smell offensively when dug into, this being chiefly due to the presence of matter from the shambles. A larger quantity of earth has lately been used with considerable advantage. The sale of the manure is said about to pay for its manufacture. It costs from 7s. 6d. to 10s. a cubic yard to make, and sells at 10s. a cubic yard. The analysis of a sample (First Report of Rivers Pollution Commissioners, 1868, vol. i. p. 50) shows that it contained only ·207 part of total combined nitrogen, and ·326 of phosphoric acid, in 100 parts; and the remark is made that "these figures indicate a practical value certainly much below that at which we had been led to estimate it by mere inspection; and it is manifest, from the very small amount of total combined nitrogen, that much of the urine escapes preservation. . . . More than 93 per cent of the finished manure consisted of

Treatment of the soil.

Addition of urine.

About pays costs.

Feeble quality of the manure

nearly worthless mineral matters and water." At Lancaster the advantages are stated to be, that an earth closet is cheaper than a water-closet, and causes less offensive smell, that "few or none of the deaths from diarrhœa and typhoid have been in houses provided with earth closets," that "fever has almost wholly disappeared from parts of the town where it was formerly rife," and that the saving of water is a considerable gain; but we must especially draw attention to the fact that in Lancaster the refuse water, which is not, as we have before stated, treated satisfactorily by this system, can be got rid of by turning it into the sea; so that this is obviously an exceptional case.

Sanitary benefits.

Easy disposal of foul water.

In his Report on excrement nuisances (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874) Mr. Netten Radcliffe says that since Dr. Buchanan's inquiry in 1869 "the system in its integrity has been adopted in many mansions and on numerous estates, as well as in not a few public and private institutions." So far as his observation went, "wherever the system had been intelligently applied and carried out, and due supervision over its working had been maintained, there its success in the abatement of nuisance from, and disposal of excrement had been assured. Where the system had been adopted without due regard to the amount and kind of labour at disposal, and the amount of supervision which could be secured, there it had failed, as any other system would have failed under like circumstances." From the same Report we find that—

The working of the system.

With the exception of the Corporation of Edinburgh, which has recently introduced public earth closets into that city . . . the Corporation of Lancaster is still, as at the time of Dr. Buchanan's inquiry, the sole sanitary authority (so far as transpired during this inquiry) which has adopted the dry earth system, and in this case the adoption is only partial. When Dr. Buchanan visited Lancaster 90 earth latrines, serving for 200 privies, and 450 houses were under the control of the Corporation. The number of earth latrines is now 120, including the latrines serving for a large school, and the houses thus provided number 500. The dry earth system, although continued within these limits by the Corporation, is not now being extended. For new houses water-closets are adopted. The latrines are mainly old midden-steads roofed in. The dry earth is stored up in one part and replenished from time to time. Once a day a servant of the Corporation visits the latrine and shovels over the excrement and urine deposited since his last visit a sufficient quantity of dry earth. The quantity of dry earth used weekly for the latrines amounts to 22 loads, each load weighing from 23 to 24 cwts. The earth is obtained from the foundations of new buildings, and about eighteen months' stock is in store. Street sweepings are occasionally substituted for or used with it. . . . The contents of the latrines are removed every six or seven weeks, and carted to the Corporation yard, where they are mixed up with blood offal from the shambles and street sweepings, and stacked in an open shed until required by the farmers. It was reported in 1869 that subsequent processes of preparation were adopted of a kind that formed no part of the dry earth system proper; but in 1869 these processes were at least carried out at such a distance from the town as not to create a nuisance. Now, in the Corporation yard, they are effected in close and very improper proximity to houses. At the time of my visit a great pile of manure, giving off a pungent offensive odour, was awaiting sale. In 1869, the manure sold for from 7s. 6d. to 10s. the ton. The selling price is now 3s. a ton, and this fact as well as the consideration that the time will probably come before long when earth must be bought for the latrines, instead of, as now, being simply obtained for the cost of carting, has no doubt largely influenced the judgment of the Corporation in ceasing to extend the dry earth system. The sanitary gain from the latrines, measured by diminution of excrement nuisance, and as compared with the old midden-stead, is very considerable. (*Loc. cit.* pp. 218, 219.)

Earth-closets at Lancaster.

System not extended.

Street sweepings substituted for or used with the dry earth.

Manure produced offensive.

Price of the manure.

The sanitary gain.

The advantages claimed for this system are, that when properly managed it disposes of the excremental matters without any nuisance or injury to health, and produces a manure sufficiently valuable at least to pay the expenses of the management of the system; that in the poorer districts, where supervision is always necessary, the earth closet affords especial advantages over the water-closet, in being cheaper in cost, requiring less repair, not being injured by frost nor by

Advantages in poorer districts.

improper substances thrown down it, and in greatly reducing the quantity of water required. Such of these points as have not already been considered will be referred to in the account of water-closets. It is maintained that a great advantage is to be found in the fact that all the manurial value of the excrement is retained in a form in which it can be easily carried about from place to place, and in which it is especially fitted for agricultural purposes.

(See "Water closets.")

Portability of the manure.

But in retaining all the manurial value of the excrement, the compost can only retain what is there, and we must remember that the fæces only contain one-seventh part of the total valuable constituents of the excreta. That it has been found to constitute a very suitable manure, and to give very good results, there is plenty of evidence to show; that unless much urine is collected with it, it cannot be really valuable, is also certain. We have seen that at Lancaster, where it is carefully watered with the urine collected from house to house, it is only a feeble manure, as shown clearly by its chemical composition; and the ready sale of any such compost (unless containing much urine) only shows how much false guano there must be in the market.

Valuable only if it contains much urine.

As to its especial fitness for agricultural purposes, there is no doubt that all solid manures are less suitable than liquid ones containing the same manurial constituents. (See the evidence from India.)

Liquid manures better than solid ones.

Dr. Buchanan calculated that the original outlay of a town of 1000 inhabitants, in changing from outside privies to the earth closet system, need not exceed £250, and the weekly expenditure £4 : 15s. If the earth were used once there would be an annual income of £365 against an expenditure of £260; if four times

Estimation of profit and loss.

it would sell at £3 a ton, and produce an income of £600 with an expenditure of £244. But in the only town where it has actually been tried, with diminished expense from separate collection of urine, it only just pays its costs.

From the Report for 1871 of the British Association Sewage Committee, it appears that Dr. Gilbert on behalf of the Committee made some trials with Moule's earth system.

Fourteen hundredweight of air-dried and sifted clayey soil were set apart for the experiment. From one half to one third of the whole was used before it was necessary to empty the pit. When removed the mass appeared uniformly moist throughout, and (excepting in the case of the most recent portions near the surface) neither fæcal matter nor paper was observable in it: nor was the process of emptying accompanied by any offensive smell. After exposure and occasional turning over on the floor of a shed, the once used soil was resifted, and again passed through the closet.

No offensive appearance or smell.

The percentage of nitrogen in the air-dried and sifted soil was found to be, before use ·067; after using once ·216; after using twice ·353.

Percentage of nitrogen in the soil.

Calculated upon the air-dried condition, the increase in the percentage of nitrogen was only about ·15 each time the soil was used; and even after using twice, the soil was not richer than good garden mould. It is obvious therefore that such a manure, even if disposed of free of charge, would bear carriage to a very short distance only. It may be added that the percentage of nitrogen in the soil after using once, as given above, agrees very closely with that recorded in the Report of the Rivers Pollution Commissioners, as found by them in the manure obtained, under professedly the same system, at Lancaster.

"Not richer than good garden mould."

The Committee remark in conclusion that,

When it is borne in mind how small is the proportion of the nitrogen voided in the twenty-four hours that is contained in the fæces, how small is the proportion of the total urine that is passed at the same time, and how great is the dilution of the manurial matters by the amount of soil required, it is by no means surprising that the manure produced is of such small value as the results would show. It is obvious too, that our domestic habits and practices would have to be entirely revolutionised to secure the collection and absorption of the whole of the urine, which contains by far the larger pro-

Manure produced of small value.

portion of the valuable manurial matters voided. Moreover, assuming 2 or $2\frac{1}{2}$ lbs. of soil to be required for each use of the closet, if the whole of the liquid, as well as the solid excretal matters, were to be absorbed, there would probably be required from 9 to 10 lbs. of soil per head per day, or about $1\frac{1}{2}$ tons per head per annum. This for London, taking the population at $3\frac{1}{4}$ millions, would represent a requirement of about 5 million tons of soil per annum, or nearly 14,000 tons per day; and the quantity to be removed would of course be considerably greater. This illustration is sufficient to show the impracticability of any such system for large populations. Nevertheless it may readily be admitted, that it would be of great advantage in a sanitary point of view, in the cases of sick-rooms, detached houses, or even villages, and that it might be even economical where the earth for preparation and absorption, and the land for utilisation, are in close proximity. (*Loc. cit.* pp. 187, 188.)

Quantity of soil required for London.

System advantageous in some cases.

In the Report of the same Committee for 1874 (p. 213) are given the results of further analyses obtained by Dr. Gilbert, by the soda-lime method. Thus the percentage of nitrogen in the soil dried at 100° C. was found to be, before use ·073; after using once ·240; after using twice ·383; after using three times ·446; after using four times ·540; after using five times ·614. The quantity of nitrogen existing as nitrates in the soil, after being used five times, was found by Dr. Russell to amount to ·20 per cent when the soil was fully dried. "Supposing the whole of this to be in addition to that determined by the soda-lime method, the total nitrogen in the soil would be raised to ·814 per cent—still, therefore, to considerably less than 1 per cent in the fully dried condition, and scarcely $\frac{3}{4}$ per cent in the air-dried condition." The Committee then say, as in the former Report, of the twice-used soil, that:—"Such a manure, even if disposed of free of charge, would bear carriage to a very short distance only." The Committee observed, however, "that the process of emptying was still unaccompanied by any offensive smell, and that the soil after drying on the floor of a shed, could scarcely be

Percentage of nitrogen in the soil.

Quantity of nitrates.

No offensive smell

distinguished from ordinary mould." The average gain of total nitrogen to the soil, by each passage through the closet, was scarcely ·15 per cent. The Committee remark, on this point, that, "if only two pounds of soil were used per head per day, and as much as one third of the total nitrogen voided in fæces and urine by an average individual in twenty-four hours, were collected with it in the closet, the nitrogen so added to the soil would amount to about ·5 per cent of its weight by each use, or by using five times, to nearly 2·5 per cent. Probably in practice, a larger amount of soil, and a smaller proportion of the total nitrogen daily voided, would be collected in an earth closet. The increased percentage of nitrogen actually found, is seen to be less than one third of the amount, calculated on the foregoing assumption. There can indeed be little doubt that there is a considerable evolution of nitrogen in some form; and the probability is, that it takes place to a great extent as free nitrogen." (*Loc. cit.* p. 214.) Average gain of total nitrogen. Evolution of nitrogen.

As to the value of the manure produced by the passage of the earth through the closet, whereas the Sewage Committee of the British Association reported that the soil which has been used five times is "no richer than good garden mould," and "would bear carriage to a very short distance only, even if disposed of free of charge;" and Dr. Voelcker estimated the value of such a soil (used five times) at 7s. 6d. per ton (*Journal of the Royal Agricultural Society*, No. 15, 1872, p. 185); it is stated in Mr. Radcliffe's Report before mentioned that Mr. Walters, the manager of the model farm and cottages of the Hereford Society for Aiding the Industrious, finds a ready sale for the soil passed three times through the earth Value of earth closet manure. Dr. Voelcker's estimate. Mr. Walters' statement.

closets of the cottages, in small quantities for garden purposes, at the rate of 6s. per cwt. (£6 per ton), between two and three tons being sold at this price in the course of a year. The difference between these figures is so enormous, that the only possible explanation lies in the fact, that the quantity sold on the Hereford Society's estate is too small to afford any data for arriving at the true commercial value of the soil as a manure.

Difference inexplicable.

The Messrs. Girdlestone, in pointing out the duties of the scavenger in villages supplied with these closets, state that "the dry earth system and the water system could be made to work together in a village where a general adoption of the former could not be carried out;" and also admit that "in addition to the obnoxious refuse which the earth system treats, there are in all habitations the liquid refuse substances of the kitchen, the washhouse, and the chamber, to be provided for." They suggest that *light and inexpensive sewers* should be made to carry them away, or that they "may be conveyed, by *sub-irrigating drains*, into the soil of the adjacent gardens, and there used as a valuable supplementary manure;" and that in the former case this liquid refuse should be partially purified before reaching the street sewer, by draining it through some available medium, such as a compost heap in which ashes would be a principal ingredient, and by the use of disinfectants where these might appear to be necessary. They point out that "the small system of drains required for the liquid refuse, if earth were applied to the extermination of the solids, would not require more than one-third of the cost bestowed on drains under the water system." That this would not be the case we shall show in due time (p. 178).

Water system as well, in some villages.

Necessity of sewers, and of irrigation.

Compost heap to purify the refuse water.

Captain Drake sees the difficulty of a separate drain system, and actually suggests in his letter to the *Lancet* (24th July 1869) that "the refuse water from kitchen sinks, etc., should be drained *into cesspools,* accessible to a cart in the same way as the latrines. It can then be pumped into a cart and removed."

Cesspools for the foul water.

This suggestion speaks too strongly for itself to need any additional remarks.

The Rev. Henry Moule, in his pamphlet on "The Science of Manure as the Food of Plants," states that the liquid refuse of his house was at first conveyed by drain-pipes into a tank in his garden, but that, especially in sultry weather, the contents of this tank fermented and became exceedingly offensive. He then interposed, between the house-pipes and the drains, tubs with holes in the bottom and nearly filled with earth mixed with a small portion of coal ashes. This method sufficed to prevent the offensive smell from the tank "*so long as the earth was frequently changed;* but, if the earth continued to be so used more than forty-eight hours, ammonia was soon perceptible in the one tub, and from the other there arose a most fœtid smell." Such a method as this might answer very well with careful management in cottages and in detached country houses.

Offensiveness of water tank.

Filtration how far successful.

He considers that "the removal of such refuse from houses, whether detached *or in villages and towns,* is perfectly feasible;" while in a letter addressed to the Editor of the *Hertfordshire Express,* he states that "in a town standing, for instance, as Epping does, the whole of both bath and slop and sink water may be disposed of *by sub-irrigation* on ten or twenty acres of land at each end of the

Refuse water utilised by irrigation.

town, and by it the land be made worth £20 per acre." *

From all these statements, made by the supporters of the system be it observed, it is evident that, as in all other systems which keep the excremental matters from the sewers, a special arrangement has to be made for the treatment of other refuse matter which is too valuable to be lost, not to say anything of its rendering the sewage unfit to be allowed to run into a watercourse. The plan proposed by Mr. Moule to meet this difficulty could obviously not be applied in towns, however well it may act when carefully conducted in country houses; although even under these favourable conditions it is questionable whether persons who have not a special predilection for the system would consent to have buckets of earth and ashes placed as filters for the slops, the contents of which buckets are acknowledged to become offensive if they are not changed regularly every forty-eight hours; but the other suggestion, namely, that this liquid refuse might be disposed of by sub-irrigation on a few acres of land, is much more important, inasmuch as it acknowledges that, practically, the earth closet system has not solved the question of entire removal of refuse matters, but that, even with it, some irrigation system is required. The suggestion that the sewers might be made of much lighter construction and at a much smaller expense, if the earth closet system were in vogue, can hardly be accepted unless it be admitted that even under this system it would be advisable to have sewers provided for the slops and liquid refuse generally *apart from the drains provided for the rainfall and the subsoil drainage,* otherwise the difference in the size

Plan of filtration not feasible in towns.

Obvious fatal objections.

Acknowledgment of failure to deal with liquid refuse.

No diminution in size of sewers.

* See also pp. 125-131.

and construction of the sewers and in their cost could amount to next to nothing; the great size that they have to be made when used, as is generally the case, both as drains and sewers, being necessary chiefly to provide for a sudden excessive fall of rain. We come then to this dilemma—either two systems of sewers must be supplied, or, the liquid refuse being received into the one system of drain-sewers and mixed with the whole of the drainage water, this quantity must be purified in some way at a great expense, although its value as manure would have been diminished by precisely the amount of fertilising ingredients that had been kept from the sewers by the dry closets. Dilemma.

In fact, as far as the Utilisation question is concerned, there is a greater necessity for two sets of sewers with the earth closets than without them. Two sets of sewers necessary.

The general conclusion come to by Dr. Buchanan and Mr. Radcliffe is, that "the earth system affords a second way of safely disposing of excrement. It is . . . an essential element in this system also, as applied in poor neighbourhoods, that the entire management of it shall be conducted by the sanitary authority. (*Twelfth Report M. O. P. C.*, p. 140.)

Dr. Buchanan, at the end of his valuable Report (see *Twelfth Report M. O. P. C.*), brings forward and discusses the objections that have been made to this system. They are as follows :—

1. That for private houses water-closets are thought to be cleanly, earth closets to be dirty. This objection may appear to be trivial, but we are afraid that it will be found to be a very practical one, and that it is not made without good reason. We have already seen that even in Halton, where these closets were "under the same roof with the house," the occupiers actually Objection that earth closets are looked upon with aversion

refused to use them, and preferred their garden privy with its stinking cesspool. This must have been either because they had used them and found them, when so situated, to be a nuisance, or because there was to their minds a sentiment of uncleanliness in having the improved privy in such close proximity to their dwelling rooms. We expect it will be found that many other people will share this feeling with them, and that this objection will therefore be found a very potent one.

Here we may quote the late Dr. Parkes :—" Until there is greater evidence about the complete deodorisation and innocuousness of the mixed soil and earth when retained in houses (especially in the tropics), it would be desirable to have the earth closets always external to the houses, and if possible the soil should be removed daily." (*Hygiene*, 2d ed., p. 332.)

Earth closets should be outside the houses.

2. That the earth closet gets out of order. This objection is answered by a reference to the schools and jails in which the system is at work, and it is pointed out that with supervision these closets do not get out of order, while water-closets in the poor parts of all large towns may almost be said to be never in order. We must at once insist that it is not fair to compare closets over which a daily careful supervision is exercised with others which are supposed to work by themselves, and to require no supervision whatever, and so are left to the tender mercies of careless persons. It should be pointed out, that were the earth closets to come into general use, it would be absolutely impossible to prevent bedroom slops and so forth being thrown down them, especially in the case of closets in the upper floors of houses in towns, in which case it is obvious that the pit into which the

Must not compare things unfairly.

pipe from these upstairs closets is to descend directly would simply become a cesspool, with the additional disadvantage over the old-established cesspool, of not having any pretence at a mechanism for keeping noxious gases from getting into the house; in fact, wherever liquid refuse got thrown into the earth-closet, either upstairs or downstairs, the receptacle would become no better than a cesspool, without the advantages of a well-constructed one.

Earth pit would often become a cesspool.

3. That it is not applicable within houses, especially above the ground floor. There can be no doubt that this is not a valid objection, except indirectly, for the reasons we have just mentioned.

Invalid objection.

4. The quantity of earth required in the case of towns would be too great. With regard to this point Dr. Trench states (*First Report R. P. C.*, 1868, vol. ii. p. 305) that Mr. Bateman has calculated "that for London the amount of soil required will be 2,000,000 cubic yards a year, which would necessitate the digging of 200 acres to the depth of 6 feet, or 400 acres 3 feet deep, every year. The amount required in Liverpool, calculated on the same ratio for population, would be 400,000 cubic yards, or the digging of forty acres to the depth of 6 feet, or eighty acres to the depth of 3 feet." If one of the objections to the pail system be found in the blocking of the streets by the scavengers' carts, this objection must hold with increased force where not only the excremental matters have to be removed, but so enormous a quantity of earth has to be brought into the town and taken out again. Mr. Moule indeed believes that this may be done "*without any increase of traffic in the streets*," by some underground method. Whether it would be likely to cost less, or even as little, to

Amount of earth which would be required for London.

Removal under-ground.

make underground tunnels communicating with the lowest part of every house in a town, tunnels which to be of any use would have to be sufficiently large to allow the construction of a tramway in them, as to use the existing sewers for the removal of excrement, or even to construct a special set (as proposed by Mr. Menzies) of pipe-sewers for this purpose, and leave the large old sewers for drainage, we leave the reader to judge for himself.

Petten-kofer's objection.

5. The objection of Professor von Pettenkofer, brought forward by Dr. Rolleston in the *Lancet* of 6th March, 1869, that he fears the greatest danger from the earth system, especially as regards cholera. With regard to this objection, Dr. Buchanan points out that all the evidence from India, especially "in respect of cholera," is in the opposite direction. Dr. Rolleston thinks that because the soil is deodorised it is not therefore rendered innocuous. To this the supporters of the earth closet system reply, that the presumption is in favour of the contrary opinion, and that no facts have been brought forward against it. Dr. Rolleston, however, in defence of his position, has quoted Dr. De Renzy's statement in the Fourth Annual Report of the Sanitary Commissioner with the Government of India, 1867 (Calcutta, 1869), p. 211, par. 440:—

Dr. Rolleston's opinion.

Dr. Mouat states that "although adynamic fevers may occur occasionally in an endemic form, they will never become contagious so long as the present conservancy arrangements be obtained." Actual experience has, unfortunately, already falsified this prediction. In 1866 the fever appeared with all its former virulence in the Umballa jail, and caused 48 deaths out of a strength of 698 convicts, and last year it appeared in the Peshawur and Rawul Pindee jail. Nowhere, I venture to say, is the dry earth system carried out to greater perfection than in the Punjaub jails, *but the fact remains that in spite of the most thorough deodorisation of excreta, the contagiousness of jail fever remains unchanged.*

Facts with regard to fever in jails.

He also quotes the Report of the Sanitary Commission for Madras, which states that—

Expense and difficulty.

The expense attending anything like a system of conservancy upon the dry method is enormous, and even in carrying it out to the extent that is now done, the greatest difficulty is experienced in disposing of the refuse. It was formerly deposited upon waste land in several localities, but these became such intolerable nuisances that it was necessary to adopt other means.

Nuisance caused in Madras Presidency.

It has been seriously proposed to burn the refuse matters, but now the question of employing them by irrigation is being considered.

Danger of moisture.

Dr. Mouat's own evidence states that "when the admixture with earth is carelessly performed, or where the earth used contains a large amount of moisture, the fermentation of excrementitious matter will take place, and disease will be the certain and sure result."

This objection, then, can hardly be considered to have all the facts against it; in fact, in a variety of different ways the *cabinet inodore* would become a stinking cesspool, and an especially dangerous one.

Risks to health from defective working.

The great practical objection which must entirely condemn the system, viz. that it only removes a small part of the refuse matter, has been discussed at length already (see pp. 102-106). We are quite content to accept the opinion of Colonel Ewart, quoted as follows by the Messrs. Girdlestone when contrasting the Milan and Paris methods of water-tight carts with the dry earth system:—"That no scheme of town drainage can be recommended which is dependent on mechanical arrangements of great complexity, and in which *serious risks to health would be incurred if any fracture or defect were to arise in the machinery used, or any of those failures were to happen which are necessarily incidental in practice to such a scheme*" (*The Dry Earth System*, p. 29); and we would submit that the words we have italicised are at least as applicable to the dry earth closets as to the improved Paris cesspools, which latter do not at any rate depend, as the former do *entirely*, upon the continuous and sufficient supply of an extraneous material of a particular quality and in a particular condition.

The Committee of the British Association on the Treatment and Utilisation of Sewage arrived at the following conclusions (Report 1873, p. 449) :—

Conclusions of the British Association Committee.

All conservancy plans, including midden-heap and cesspool systems, dry ash and dry earth closets, pail-closets, etc., are quite incompetent as solutions of the general question of the removal of the refuse matters of a population. Such plans deal with only a small part of the liquid manure ; towns which resort to one of them require therefore to be sewered, and the sewage requires to be purified. The manure produced is in all cases (except in that of simple pails or tubs where no extraneous materials are added) poor, and will only bear the cost of carriage to a short distance, taking into consideration the cost of collection. That produced by the dry earth system is, even after the earth has been used four times over, but little better than a good garden-mould. Such plans, moreover, all violate one of the most important of sanitary laws, which is that all refuse matters which are liable to become injurious to health should be removed instantly, and be dealt with afterwards. With all these plans it is an obvious advantage on the score of economy, to keep the refuse about the premises as long as possible ; and the use of deodorants of various sorts, or even of disinfectants, proves that this is the case, and that these systems all depend upon a fallacious principle. They should therefore be discouraged as much as possible, and only resorted to as temporary expedients, or with small populations under exceptional circumstances.

Let us finish the description of this system with two quotations—one from the paper of Messrs. Lawes and Gilbert, already referred to (see p. 54) :—

Obvious objections.

Very obvious objections to such a system are the difficulties of the supply and preparation of the soil in the case of towns, or even in the country, in wet seasons ; the fact that but little of the urine (containing as it does so large a proportion of the valuable manurial constituents of human excretal matters) would reach the compost so prepared ; and that in the manure produced, the more valuable matters would be diluted with so large a proportion of comparatively useless material, that beyond a very short distance the cost of carriage would be all that the manure was worth. On the other hand, that the adoption of such a system would be a great improvement in a sanitary point of view, in the cases of sick rooms, detached houses, or even villages where the water system is not available, and that it might be even economical, where the earth for preparation and absorption, and the land for utilisation, are in close proximity, may perhaps be readily granted ; but we are certainly not so sanguine as the Rev. Mr. Moule, who seems to think that, with the aid of earth closet companies, his plan is as practicable for large towns as is the supply of water, gas, and coal at present, and much more so than the removal and utilisation of dilute town sewage.

A sanitary improvement, and economical in some places.

And the other from the First Report (vol. i. p. 50) of the Rivers Pollution Commissioners, 1868, who, having remarked on the special service and attention which these closets require, thus conclude,

Opinion of the Rivers Pollution Commissioners.

Add to these circumstances the enormous aggravation of all the difficulties of the plan, when not 50 but 50,000 households have to be provided with the necessary appliances and induced to work them properly, and we can have no hesitation in pronouncing the dry earth system, however suitable for institutions, villages, and camps, where personal or official regulations can be enforced, entirely unfitted to the circumstances of large towns.

There can be no doubt that a well-managed dry earth conservancy system, or midden and ash-pit system, is better than no system at all, but it by no means follows that they are free from danger. They both go upon a wrong principle: we do not want conservancy at all; our first object must be to get rid of refuse-matters, and not to see how long we can keep them about our houses in a *presumed* harmless condition.

Summary.

THE DISPOSAL OF SLOP-WATERS IN SMALL VILLAGES.

In villages where there is no public water supply, each house obtaining water from its own private well, the quantity of water available is often insufficient for the proper supply and flushing of water-closets. In such villages, where the privies and cesspits have been

Difficulty in disposing of the slop waters in villages without nuisance.

replaced by pail, earth, or charcoal closets, there is the difficulty of disposing of the slop waters, which are usually allowed to run off into open ditches, there to stagnate and give rise to offensive emanations, or into "sumpt" holes in the garden, generally not far from the cottage door, into which also organic refuse of various kinds is thrown, thus causing a permanent and serious nuisance. Sometimes the waste waters are allowed to flow into streams which they pollute almost as much as if the solid excreta were mixed with them. Where the cottages have gardens the slop-waters may be disposed of and utilised by sub-irrigation, and only a very small piece of ground is required for this purpose (Mr. Rogers Field considers that four perches is sufficient for an ordinary cottage).

May be utilised by sub-irrigation.

In Mr. Netten Radcliffe's Report on Excrement Nuisances (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874) we find an account of various methods of effecting this purpose.

Slops ladled out from a store-tank.

In certain new cottages at Halton, Bucks, on the estate of Sir Anthony de Rothschild, the slops are conducted by a drain to a small water-tight receptacle in the garden, whence it is proposed that they shall be ladled from time to time for garden purposes. These cottages are provided with earth closets, and each cottage has attached to it 40 poles of garden ground. It is calculated that the manure from the earth closets and the slops may be all utilised in gardening this plot. Another method of disposal is followed at the cottages of the Industrious Aid Society, Hereford. Here sub-irrigation is used to get rid of the slops. Each cottage has a garden plot of a sixth of an acre, and in this plot sub-irrigation drains are laid for the slops with small catch-pits at intervals. The slops, however, except when in large quantities, as the contents of a washing tub, penetrate but a very short distance into the drains. The porous loamy soil readily absorbs the liquid, and no nuisance arises.

Sub-irrigation drains with catch-pits at intervals.

A third method is carried out at the Rev. Henry Moule's house at Fordington, Dorset.

The liquid refuse of the household flows to a catch-pit in the garden, which has an overflow into a sub-irrigation drain. The garden is cultivated by alternate cropping, the only manure applied to it being the fresh slops which are ladled from the catch-pit and distributed to the garden daily. Luxuriant successive crops of garden vegetables are obtained in this manner, and Mr. Moule is of opinion, as the result of his experiments, that the liquid refuse of a family of from seventeen to twenty persons can be thus profitably used on 5 or 6 perches of ground, as many as three or four crops being grown yearly.

Ladling and sub-irrigation.

Mr. Radcliffe observes, "so far as this inquiry is concerned the method described appeared to be a very feasible way of obviating nuisance from slops, where garden ground and intelligent labour were available for its adoption."

A fourth method of disposal of slops, in which the difficulty of sub-irrigation by gravitation, from the smallness of the ordinary flow, is overcome, has been invented by Mr. Rogers Field. The slop-waters are conveyed outside the house by the sink waste-pipe to a flush-tank. This tank is cylindrical and made of iron or stoneware. At the top is a movable cover and grating which is connected with a trapped inlet, the slop-waters entering through this grating and inlet. The tank is ventilated by a special pipe. The outlet consists of a siphon so arranged that no discharge can take place till the tank is full. The inner end of the siphon begins some little way from the bottom of the tank, so that sediment at the bottom is not drawn through the siphon, and for this purpose it is also protected by a wire strainer. The outer end of the siphon is continued considerably lower than the inner end, and enters a discharging trough, which is provided with a weir, in which is a notch, so as to keep back a little of the water, over which the siphon ends. The notch in the weir is intended to drain away most of the water after the tank has discharged, and thus unseal the trap at the outer end of the

Sub-irrigation drains connected with an automatic flush-tank.

Description of flush-tank.

Action of flush-tank.

siphon, putting it out of action. If the outer end of the siphon were still to remain trapped after discharging, it would be what is known as "self-contained," and liable to discharge continuously a weak and feeble current quite ineffective for flushing purposes. As soon as the tank is full some of the liquid passes through the siphon, fills up the discharging trough faster than it can escape by the notch in the weir, and traps the outer end of the siphon. The flow of water continuing carries air along with it which bubbles up from the outer end of the siphon, and this is soon sufficiently exhausted of air to be brought into action by the preponderating atmospheric pressure upon the surface of the liquid in the tank. This tank differs in action from that invented by Mr. Field for the purpose of discharging clean water, in which there is an annular siphon with an inverted lip at the top of the discharging pipe, in that the flow of water required to start the siphon action is considerably greater. A very small but constant dribble will start the annular siphon, but a considerably greater impetus is required to set in action the tank above described, a condition which, in conection with its use as a discharge tank for house waste-waters, is probably, in practice, never absent.

The liquid discharged from the tank passes into 2-inch agricultural drain pipes, laid at a depth of about 12 inches in the soil, upon a bed formed of larger agricultural pipes divided longitudinally in halves. These sub-irrigation drains are connected with the flush-tank by a longer or shorter portion of water-tight drain, according to the position of the irrigated land with reference to the house.

Sub-irrigation drains.

From Mr. Netten Radcliffe's Report, we find that, The foregoing invention for separate houses has been further developed, so as to meet the general wants of a community, by Mr. Bailey Denton, in conjunction with Mr. Field. The same difficulties have been experienced in dealing with and utilising readily, economically, and inoffensively, the liquid refuse of villages and towns, as with that of separate houses, and from the same causes, the ordinary insignificance, and occasional irregularities of flow. To meet these difficulties Messrs. Bailey Denton and Rogers Field have designed a tank, termed by them the "Automatic Sewage Meter," which is constructed on the same principles as Mr. Field's flush-tank. This meter provides for the accumulation of the liquid refuse, and for its automatic discharge, at definite intervals, in quantities admitting of distribution over land by gravitation, for purposes of irrigation. Automatic "sewage meter."

A meter of this kind has been in use about three years (1871-1874) in the hamlet of Eastwick near Leatherhead (Mr. Radcliffe's Report, 1874). The sewage and liquid refuse of a mansion and farm homestead, the drainage from cattle sheds and stables of the farm, and the liquid refuse of thirteen cottages (where improved midden-pits receive the solid excrement) is conveyed to the meter, which has a capacity of 500 gallons, and discharges in ordinary weather three times in two days. The several discharges are received on different portions of a plot of ground, prepared for the purpose, and which, measuring 3 roods 3 perches, serves ordinarily for the effective and profitable utilisation of the whole liquid refuse of the several cottages, the mansion, and the farmstead. Luxuriant crops have been grown upon the irrigated land. Mr. Hutchinson, the steward of the estate, estimates the yearly value of the crops obtained at £25, or at the rate of £32 : 10s. per acre, and the outlay in attendance upon the land and meter as £7 : 16s. Luxuriant crops grown. Yearly value of the crops.

Mr. Netten Radcliffe says,

In regard to abatement of slop nuisance, and I may add also largely of farm nuisance, among a rural community, the arrangements at Eastwick are the most complete and satisfactory I have yet seen. Notwithstanding the contiguity of the irrigated land to the mansion, no

No nuisance.

nuisance is experienced from it, whereas previous to the present arrangements, when the slops of the mansion and cottages found their way into neighbouring ditches and decomposed there, considerable nuisance had existed. With some structural alterations in the privies . . . the arrangements at Eastwick may be regarded as a pattern to be followed by villages and small towns similarly circumstanced. From what has already been said, it may be inferred that the "Automatic Sewage Meter" admits of wide application, in removing the difficulties which often beset the disposal of the sewage of communities larger than Eastwick. It simplifies the whole question of dealing with the sewage of small towns, villages, isolated institutions and mansions, while securing the most efficient application of the sewage to land, both for purification and utilisation, with the least expenditure of labour. . . . All these methods dispose of the slops by distributing them to the soil either upon, or beneath the surface, or in both ways intermittently, —in other words by intermittent irrigation.

Arrangements at Eastwick a pattern to other villages.

Application to soil intermittent.

As regards the disposal of liquid house refuse, other than on or through land, it appears from Mr. Radcliffe's Report (p. 170) that "Dr. Francis Bond of Gloucester believes that it is quite practicable to depurate liquid house refuse before it leaves the premises, so that what flows away shall not be productive of nuisance. This he purposes to effect by subjecting the refuse to a combined process of straining, chemical precipitation and filtration. The apparatus for the purpose consisted of an ordinary water-butt with a simple strainer at the mouth, and floating filter within." The precipitating substance used by Dr. Bond is termed by him cupralum, and is a mixture of cupric dichromate and aluminic sulphate with terebene.

Disposal of slops by chemical precipitation and filtration.

Slop waters and liquid house refuse being nearly identical in composition and behaviour to precipitating agents with ordinary sewage, and seeing, as we shall, that every attempt to purify and utilise sewage by chemical precipitation and straining processes has failed, it is not difficult to predict that any attempt to deal with these waste waters in a similar way must also end in failure.

Method must fail to purify effectually.

On the whole then, we are of opinion that for villages which are not provided with a general system of sewerage, the best plan for the disposal of the refuse matters is the adoption of earth closets under careful and systematic supervision, and the provision of self-acting flush-tanks for the disposal of the slops and waste water by sub-irrigation drains. Summary.

CHAPTER V

WATER-CLOSETS AND WATER SUPPLY

WE have seen that in many towns it has been found advisable to connect the cesspools with the already existing drains. It is hardly necessary to point out that drains exist, or ought to exist, in every town or village for the carrying away of the surface and subsoil water and refuse of various kinds.

Drains necessary.

We have also said that by this connection of the cesspools with the drains the principle of a cesspool is entirely abolished and its use not easily seen. In fact, if any part of the decomposing materials from excrement be allowed to pass into the drains of a town, it is difficult to see why the whole of it should not be allowed to do so. By interposing a cesspool between the privy and the drain, we form a collection of putrefying matter in the close vicinity of the house, and with this system the inhabitants of towns may be well said to be "living on a dungheap." On the other hand, by connecting the privy directly with the drain, the refuse matters pass immediately away from the house, and so from the town.

Why retain cesspools?

It has, however, been found necessary, in order to ensure this passage being as quick and perfect as possible, that water should be thrown down the privy, in order that the refuse matter may be washed away at

Water necessary to ensure speedy removal of excreta.

once, and so water-closets of various forms have come to be established in most towns.

In the First Report of the Health of Towns Commission (1844) special attention is given to the question of the desirableness of the change of middens and cesspools into water-closets. Such opinions as the following are continually expressed by the witnesses examined by these Commissioners:—

> Water-closets should be substituted for necessaries, and no accumulation of excrement allowed. . . . It is evident that the only complete remedy is to prevent the accumulation of manure in such large quantity in the immediate neighbourhood of dwellings, by washing it away into the sewers, that is by the erection of water-closets in all cases where houses are built closely together; where great economy is important, a very simple form of water-closet would suffice. (*First Report*, vol. i. p. 212.)

Prevention of accumulation of refuse desirable.

Again—

> The general adoption of apparatus of the nature of a water-closet would be an immense stride to general cleanliness, and would unquestionably diminish by three-fourths the pernicious exhalations that emanate from all the courts, alleys, and backyards of the town. It would also abolish the obnoxious employment of night-soil collecting, which is not only injurious to the health of the persons engaged in the trade, but is likewise detrimental to the community at large. (*First Report*, vol. i. p. 306.)

Obvious advantages of speedy self-acting removal.

At Liverpool, where there was a clause in the Sewerage Act against the connection of soil-pipes from water-closets with the public sewers, it was found to be constantly evaded, thus showing the importance to the inhabitants of that communication. The reason given for this prohibition was that it was a question—

Evasion of a bad regulation.

> Whether the filth and soil from water-closets being allowed to go into the sewers and thus pass through a great portion of the town, emitting noxious smells to escape from the eyes of the sewers, is not more detrimental to the general health of the inhabitants than when it runs into cesspools upon the premises of the occupants, and emptied only when necessary, because the cesspools can be so constructed as to be perfectly air-tight, and prevent any escape unless when emptied. (*Second Report*, vol. i. p. 146.)

Why it existed.

We have already seen that cesspools practically are

Cesspools not impervious: often not intended to be so.

never so constructed, and that their contents always to a certain extent escape from them into the surrounding soil and are carried away by the drains, and that in fact in many cases they are specially so constructed that their contents shall escape as freely as possible. We shall hereafter show that the sewage of a town supplied with middens and cesspools is to all intents and purposes as offensive and as noxious as that from a town entirely supplied with water-closets; it may, indeed, be more so.

Real meaning of above argument.

But besides this, if the reason given above means anything, it means that it is more dangerous for foul water to pass through and away from a town, with some chance at any rate of no great an amount of decomposition taking place, than for it to remain for some time in cesspools under yards and houses, decomposing, and emitting nauseous effluvia continually —a manifest absurdity.

Bristol "eject."

At Bristol the outside privies are connected with the sewers, but they are not supplied with water. "They are made, not with the earthenware pan and trap, in the rough use of which by careless folks so much difficulty is experienced in other towns, but with a stone shoot and 'eject' communicating with a 9-inch pipe, and the whole well set, under rules printed by the Local Board, and acted on in practice. Certainly the stone traps or ejects often get blocked, but not more frequently (if so often) as under the customary arrangement of pan, trap and wretched water supply of the poor quarters of most towns; while the construction allows of articles that are improperly thrown into the privy being easily pulled out or flushed away." (*Ninth Report M. O. P. C.*, pp. 63, 64.)

The privy is required to be constructed according to the following rules issued by the Bristol Local Board of Health, which are given in Mr. Radcliffe's Report on Excrement Nuisances (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874):—

Rules for the construction of the Bristol eject.

The trunk of the privy to be of brickwork set in cement, and rendered on the four inside faces with cement not less than 1 inch in thickness.

The eject to be of freestone, not larger than 18 inches long, by 9 inches wide, and 12 inches deep, having the tongue standing at least 3 inches in the water.

The drain to be of 9-inch stoneware pipes, properly laid and jointed, and with a fall of not less than 1 inch in 5 feet.

The privy to be ventilated by means of an opening of not less than 9 inches square, communicating with the external air, and if the privy be situate in a dwelling house, and communication with the external air cannot be otherwise readily obtained, an air-tight trunk or shaft of not less than 9 inches square is to be provided and fixed.

All the works to be executed as the Board's Surveyor shall direct, and to his satisfaction.

The eject forms a capacious dip trap, but this freestone eject may now be replaced by a stoneware trap of a similar kind.

Advantages claimed.

The advantages claimed for this kind of privy are its little liability to get out of order from careless use or from violence, and the facility with which foreign matters, that may have been cast into it, can be removed without damaging the structure.

State of the privies.

Mr. Radcliffe examined a considerable number of these privies in the poorer parts of the city, and among the population most liable to misuse them, and found with few exceptions the ejects "free from accumulated matters, and the trunks clean and without offence." On the other hand several privies in Westbury-on-Trym, of similar construction, were found blocked, and the trunks "filled almost to the brim with excrement, and others were found foul within and most offensive." In fact the privies here were in the state in which Mr. Radcliffe had been accustomed to find other forms of water-closet elsewhere, in which flushing by hand has been depended upon, as a means of cleansing them. The difference in the state of the privies in Westbury-on-Trym and in Bristol indicated corresponding differences in supervision, management, and water supply. Three conditions are found necessary to the successful working of the Bristol privy, namely—(1) Frequent systematic inspection. (2) The sanitary authority being prepared to cleanse, and undertaking to cleanse, the privies where necessary. (3) A plentiful and readily accessible supply of water.

Conditions necessary to success.

As to the suitability of these closets for other towns, Mr. Radcliffe says,

Suitability for other towns.

> Under these conditions the Bristol privy works well in Bristol, but in judging of its applicability elsewhere, another highly important consideration should not be overlooked. The poorer population of Bristol, which most needs, and indeed absolutely requires the active interference of the Corporation in its sanitary management, is for the most part housed in small houses, which rarely contain more than two families. This gives great facility in dealing with individual houses and families, as regards excrement disposal, general sanitary management, and the control of infectious disease. The problem, in fact, of excrement disposal in Bristol is very different from that which presents itself in Liverpool or Glasgow. The number of families having access to a privy in Bristol obviously exercised a considerable influence upon the state in which it was found, as to freedom or not from filth. —(Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., pp. 207-209.)

This shows that it will not do merely to connect privies with the sewers; there must be some ready means of flushing them from time to time.

Forms of water-closet.

There are many different forms of water-closet, but for the sake of classification they may all be arranged under one of two heads. Thus in class I. we shall consider closets in which there is no special apparatus for retaining water in the basin, such being hopper and wash-out closets; in class II. closets which have some special apparatus for retaining water in the basin, such being the pan, valve, and plug closets.

Hopper closet.

The hopper closet consists of an inverted stoneware cone, connected below with a curved pipe retaining water, called a siphon trap, from the water retained being sufficient to prevent the free passage of air through the pipe. The old form of hopper closet called the "long hopper," from the length of the cone, is a bad one, from the difficulty of flushing, and the consequent fouling of the basin. A better form of this closet is a shorter cone with the back of the cone or hopper made nearly vertical, as it is found that the sloping back becomes very much soiled by the solid excreta.

Long hopper.

Better form of hopper closet.

Should be flushed from a water-waste preventing cistern.

This form of closet is best flushed from a water-waste preventing cistern, of a capacity of 2 or $2\frac{1}{2}$ gallons, placed not less than 4 feet above the seat, the service or supply-pipe to the closet being of large size, $1\frac{1}{4}$ or $1\frac{1}{2}$ inch in diameter. The water should be admitted to the basin by a flushing rim, which will cause the sides of the basin to be thoroughly washed, and the trap below effectually flushed out. Any mode of admission which causes the water to whirl round and round in the basin will not flush out the trap, and consequently some of the excreta will be left behind.

Flushing rim.

Advantages of hopper closet.

The advantages of closets of the hopper type are that they are simple in construction, inexpensive, have no confined space where foul air can accumulate, and convey slop waters away at once, there being no necessity for providing an overflow-pipe.

Disadvantages.

The disadvantages are that no water remains in the basin, and that amongst dirty or careless people, they may be, and frequently are, used again and again without being flushed, until the trap is choked up.

In the wash-out closet, the basin, which is of stone-

Wash-out closet. ware or china, is so shaped that a small quantity of water remains in it to receive the excreta. The excreta and water are flushed out of this basin through an opening at the side, front, or back into the siphon trap below, and so into the soil-pipe. Difficulty of flushing. A difficulty in this form of closet is to flush everything out of the trap beneath with 2 or 2½ gallons of water. The rush of the water from the flushing cistern is broken by the force necessary to clear out the contents of the basin, and then the water falls into the trap, but often without sufficient force to propel the excreta through the trap. Still there are several forms of wash-out closet which can be effectually flushed with 2 or 2½ gallons, and they have this Advantages in use. advantage in addition to those previously mentioned as belonging to the hopper closet, that careless people will not use them repeatedly without flushing, as the excrement would accumulate unpleasantly in the basin. On the other hand the basin is very apt to become soiled by solid matters, especially near the outlet.

Should be flushed by water-waste preventers. With these two forms of closet, waste-preventing cisterns should be used, both for the sake of economy of water, and because the water in the house cistern, used for drinking, will not then run any risk of being contaminated by foul air from the closet basin ascending the supply-pipe. Should the water be supplied by constant service, the waste-preventing cistern is especially necessary, to obviate the danger of the water in the mains becoming contaminated by the ascent of foul air or liquid filth up the supply-pipe into the water-main.

These closets must be protected from frost, as the Conditions to be secured in use. china or stoneware traps are liable to crack during very cold weather. They are best suited, too, for use in the basements of houses, where the china or stoneware traps can be directly connected with the drains. When used upstairs in connection with lead or iron soil-pipes they should either be provided with lead instead of stoneware or china traps, or special precautions should be taken to make the joint between the china or stoneware trap and the metal pipe perfectly secure (see p. 143).

The retention of a larger quantity of water in the basin is more fully provided for in the "Dececo" closet, the invention of Colonel Waring, which has been recently introduced in the United States. This is a modification of the short hopper closet, in which the ascending arm of the siphon is carried up much higher than usual, so that water stands at a considerable height in the basin: the descending arm of the siphon ends in an arrangement, the action of which is similar to that of the weir in Mr. Rogers Field's flush-tank, so that when the contents of the water-waste preventer are discharged into the closet basin, the siphon is set in action and the contents of the basin carried away. The water-waste preventer used with this closet is so constructed that the basin is recharged with water after the siphonic action has ceased.

"Dececo" closet.

Water stands in basin.

We now come to the consideration of closets of the second class, which have some special apparatus for retaining water in the basin.

The pan closet is of all forms the one that has been and is still most frequently used, and it is the worst devised, and the one which most readily and surely becomes a nuisance. It consists of a conical china basin in which water is retained by a movable metal pan; the pan is made of such a size that to allow of its swinging back to give passage to the water and excreta a large rounded receptacle, usually of iron,

Pan closet.

Description of pan closet.

is necessary, which is called the "container." A pipe passes from the bottom of the container into a trap beneath, which is usually one of the kind called from its shape a D trap. When the pan is swung back by raising the handle, the soil is thrown upon the sides of the container, where a thick layer of foul matter is soon formed, and the fœtid air resulting from the decomposition of this foul matter is forced through the opening above into the air of the closet. The D trap is also an insanitary apparatus, where foul matter accumulates and decomposes. D traps and the soil-pipes connected with them are often found to have holes eaten through their leaden walls by the chemical action of the foul air produced by the decomposing filth retained in them.

Dangers arising from use of pan closets and D traps.

Attempts to improve pan closets useless.

Attempts have been made to improve on the pan closet by substituting a stoneware for an iron container, and by ventilating this through a special pipe carried into the open air. The result is a mitigation only of the evils to which this form of closet gives rise. There is only one course to pursue, and that is to abolish a pan closet wherever found, and substitute one of those forms which better answer sanitary requirements.

Valve closet.

The valve closet, which is now being extensively used in houses of the better class to replace pan closets, consists of a bowl-shaped china or stoneware basin, with the outlet, about three inches in diameter, at the lowest part of the basin, guarded by a water-tight valve, by means of which water is retained. This valve is swung back on raising the handle into a metal valve-box or connector, allowing the contents of the basin to pass into the trap below, which is often a D trap, but should be a siphon or an Anti-D trap.

Anti-D trap less liable to siphonage.

The Anti-D trap is a variety of the siphon trap, which has a square instead of a round outlet, and it is found by this arrangement that the water in the trap is less likely to be drawn by the passage down the soil-pipe of the contents of the water-closets from a higher level.

The basin, having a water-tight valve at its outlet, is provided with an overflow-pipe, which is usually trapped by a bend and then connected to the valve-box. It is found that the water in this trap is liable to be sucked out into the valve-box when the basin is emptied, and then a passage is left which may admit foul air from the valve-box to the general air of the closet. To obviate this difficulty the following arrangements have been devised:—

Overflow-pipe from basin.

(1) To provide the overflow-pipe with a separate supply of water, so that it is flushed each time the handle of the closet is raised, and the trap on it is left charged with water.

Difficulties connected with overflow-pipes can be overcome.

(2) To separate the overflow-pipe from the valve-box, and make it discharge either into the waste-pipe of the lead safe-tray on the floor under the closet, which itself discharges into the open air, or through the external wall into the open head of some rain or waste-water pipe.

(3) To have no overflow-pipe from the basin, but when filled to allow the basin to overflow by means of a depression in its rim directly into the safe-tray, and thence by its waste-pipe into the open air.

The basin, as in the other forms of closet, should be provided with a flushing rim. In this closet the large volume of water in the basin flushes thoroughly the valve-box and the trap beneath, and the valve-box itself being of such small dimensions, there is much less danger of deposition of solid filth on its sides than in the large container of the pan closet. The valve-box is sometimes enamelled inside, by which the adhesion of filth to its sides is prevented. It is advisable

Flushing rim.

The valve-box.

that the valve-box, being an air space between the valve and water in the trap, should be ventilated to the external air by means of a special pipe.

Flushing arrangements for valve closets.

Water-waste preventing cisterns are for the most part inapplicable to valve closets, which should be flushed from a small cistern in the closet holding about six gallons of water, some form of regulating valve being used to secure an after-flush to fill the basin when the outlet valve is closed. This cistern should supply the closet only.

Disadvantages in use.

A disadvantage in the use of these closets is that the valve may be prevented from closing by a piece of paper being caught in its hinge, and that the valve after some time may become leaky, in either of which cases the water will not be retained in the basin.

Valve closet superseded by pan closet;

Siphon trap by D trap.

It is a curious fact that when water-closets were first introduced into this country about fifty years ago the Bramah or valve closet was the one at first adopted, and this was superseded by the pan closet on account of its smaller cost, the serious sanitary defects of the latter not being at that time understood. So too the D trap, a most insanitary appliance, superseded the simple S bend or siphon trap, on account of the readiness with which the water was drawn out of the latter, when the pipe into which it discharged was insufficiently ventilated.

Plug closet.

In the plug closet the entrance to the outlet-pipe, which is at the side of the basin, is closed by a plug or plunger, allowing water to remain in the basin up to the level of the overflow, which either passes through the plug, being protected by a trap of some kind, or discharges into the external air. These closets are usually provided with a china siphon trap, cast in one piece with the basin, but sometimes they are trapless.

Their chief disadvantage is that the entrance to the outlet is liable to become dirty, and being out of sight this is overlooked and a nuisance produced. Chief disadvantage.

When these or any other water-closets are not provided with traps, foul air from the soil-pipe is liable to escape into the house, especially when, for either of the reasons mentioned under valve closets, the water is not retained in the basin.

Whatever kind of water-closet apparatus be adopted the trap should be distinct from it, and so firmly connected with the soil-pipe or drain as to be, to all intents and purposes, part of this. The water-closet apparatus will then be capable of removal without disturbing the trap, and there will not be any weak joint between the trap and soil-pipe, as is frequently the case when the trap is part of the water-closet apparatus, especially when a china trap is connected with a lead soil-pipe. Trap should be distinct from water-closet apparatus.

Water-closets should always be ventilated as far as possible separately from the rest of the house. The plan of having them close to the entrance to the garden or yard, and with a door which shuts them off entirely from the hall, is an excellent one; and wherever two doors can be interposed between them and the rest of the house, it is advisable that they should be, and that the space between them should have a window left generally open; by this means air from outside enters easily, and should be allowed an exit by the closet window, or preferably by a ventilator in the roof. M'Kinnell's is an excellent one for this purpose, as it provides an easy exit for air as well as an entrance. It is not enough to have an opening by which air can go out; it is also necessary to see that it does go out by it, and that its exit is not, as is too often the case, from the closet into the staircase of the house. Ventilation.

In blocks of dwellings for the poor, "model lodging-houses," etc., the closets, sculleries, etc. should all be ventilated from the galleries, and should, wherever practicable, be entirely separated from the dwelling rooms by an open gallery.

When artificial.

In hospitals, etc. which are warmed and ventilated by special artificial means, it is very easy to ensure perfectly separate ventilation for the closets just as for fever wards.

Urinals.

Public urinals should be lined with slabs of smooth slate, or, if circular, with hard stoneware: they should not be placed in unsightly blocks at long distances apart, but should be in small clusters or singly at more frequent intervals. That they can very easily be kept quite clean and inodorous is shown by those in Paris and other large French towns; but to this end it is necessary that water should trickle down them *continually;* no great amount of water is wasted in this way, and rain water could often be collected for the purpose. That urinals cannot possibly be kept clean without a small but *constant* flow of water is amply proved in London, where the state of many of the public urinals is most disgusting, and a disgrace to the authorities who have the care of them.

Constant flow of water.

Their position and construction.

Urinals should never be placed inside houses, but in some instances, especially in hotels, clubs, etc. this cannot be avoided. Everything connected with them should be made of non-absorbent materials, as china, slate, and stoneware, and all metal apparatus and pipes, whether of enamelled iron or of lead, should be avoided as liable to corrosion. The water should be supplied from flushing cisterns, arranged to discharge automatically at regular intervals. The floor should be made of tiles set in cement and sloping to a channel discharging into a siphon trap, connected with a soil-pipe, or in some instances with a gully outside the house. Where basins are used, they should be constructed to hold water in them always, and their waste-pipes should discharge over the channel in the floor.

Soil-pipes.

Soil-pipes should preferably be of drawn lead (7 lbs. to the square foot) without any longitudinal seam. They should be circular in section and 4 inches in diameter, and should be fixed, wherever practicable, outside the house. Under certain circumstances however and with special precautions, $3\frac{1}{2}$ and even 3-inch pipes may be used. Five-inch soil-pipes, sometimes used where several closets discharge into the same pipe, are unnecessarily large, and are not so likely to be kept clean by the water discharged through them.

Iron soil-pipes.

Iron soil-pipes may be used outside the house, but never inside, as the joints between the different lengths cannot be made so sound as between lengths of lead pipe; this is especially the case where lead T pieces, to receive the branches from the closets, are fitted between the iron lengths; the joints between lead and iron being liable to become insecure.

Soil-pipe carried up above the roof acts as ventilator to the drain.

The soil-pipe should be carried up full bore to the top of the house, above the ridge of the roof, clear of all windows and chimneys, its end being left open or merely covered with a piece of wire gauze. If there be an air inlet to the drain, this pipe will act as an outlet, and the drain will be thoroughly ventilated. Therefore the foot of the soil-pipe should be connected with the drain by a plain bend, without any trap.

Foot of soil-pipe trapped in some instances.

In some instances, however, especially where the soil-pipe must be inside the house, it is desirable not to connect the soil-pipe directly with the drain, but to make it discharge into a siphon trap with an air inlet outside the house, called a disconnecting trap, and to ventilate the drain separately by means of a 4-inch pipe carried up above the roof.

Glazed stoneware pipes as soil-pipes.

Glazed stoneware pipes are sometimes used for soil-pipes, being placed one above another, with cemented joints. They have the advantage of being very smooth inside, and therefore cleanly, and also of being unaffected by chemical action; but they have the disadvantage of very numerous joints, which may be partly obviated by embedding them in cement.

Ventilation of arms from closet traps.

Where several closets discharge into one soil-pipe, it is advisable to ventilate the arms from the closet traps by a pipe starting from the upper side of the arm of the lowest closet close to the trap, passing up the outside of the house into the ventilator of the soil-pipe, above the entrance of the arm from the highest closet, and receiving a ventilating pipe from the arm of each closet on its way up. By this means the water discharged from the upper closet will be prevented from drawing water out of the traps of the lower ones, and so unsealing those traps. With 4-inch soil-pipes, $1\frac{1}{2}$-inch ventilating pipes will be sufficient to ventilate the arms of the water-closets, but with soil-pipes of smaller diameter a 2-inch pipe is necessary for this purpose.

Prevents siphonage.

House drains.

The house drain may be of glazed stoneware pipes with cemented joints, or with Stanford's patent joints, or of cast-iron pipes coated inside and out with Angus Smith's solution, with caulked gas-tight joints. With cemented joints it is important to see that each joint is wiped out on the inside of the pipes, to remove any cement that may have been pressed into the pipes, and which would, if not removed, harden and form a solid projection into the drain, against which solid matters would lodge and form an obstruction to the flow of the water.

The diameter of the drain will vary with the amount of water it may be required to carry away, but for small houses 4 or 5-inch pipes, and for larger 6-inch pipes will be required. For very large houses or institutions, especially where several outbuildings, etc. discharge into the same drain, 9-inch pipes are sometimes used, but pipes of this size are seldom required for houses, and should never be used for a single house of ordinary dimensions. *Diameters of house drains.*

Wherever it can be avoided the drain should not be carried under the basement of the house. It should be laid in straight lines from point to point, and at every change of direction means of inspection should be provided, preferably by an inspection chamber, through the floor of which the drain should be continued by a channel-pipe curved to suit the change of direction. Into such inspection chambers branch drains should discharge by means of short curved channel-pipes, emptying over the main channel. *Laying of house drains.* *Inspection chambers.*

At the point where the drain leaves the premises a disconnecting trap should be fixed, consisting of a siphon trap with an air inlet; this may be best arranged in connection with a manhole for access to the trap and drain. The drain should be continued through the floor of the manhole in the form of a channel pipe, from which the floor of the manhole should slope up towards the brick sides at an angle of about 30°. Branch drains should be connected with the manhole in the same way as with the inspection chambers mentioned above. The manhole should be covered with a stone slab, or still better with an iron door, and should be provided with an air inlet, either *Disconnecting trap, where the drain leaves the premises.* *Disconnecting manhole chamber.* *Air inlet.*

by means of perforations in the cover, or by means of a pipe taken to a suitable point and provided with an iron grating. The channel pipe should discharge directly into the siphon trap, which should not be larger in diameter than the drain, but preferably somewhat smaller. The siphon trap should be provided with an arm connected with the farther end of the trap, for the purpose of clearing out any obstruction which may occur in the drain beyond the trap. This arm, called the raking arm, should have its end closed inside the manhole with a piece of tile set in cement, which may be broken when occasion requires.

Siphon trap.

It is occasionally advisable to close up the manhole entirely, and carry a pipe from it up above the roof of the house.

Advantages.

The great advantage of this system of inspection chambers and manholes is that the drain can be inspected, cleaned, and obstructions removed, without breaking into it.

Gradients for house drains.

The gradient for house drains should be if possible not less than 1 in 40, or 3 inches in 10 feet, and preferably 1 in 30, or 4 inches in 10 feet. If the gradient attainable is very small, a siphon flush-tank should be placed at the head of the drain.

Drain laid in cement concrete.

If the soil on which the drain is laid is not very firm, the drain should be laid in a bed of cement concrete, and when running under the basements of house, should preferably be covered also with cement concrete.

Testing of house drains.

House drains, especially if they run under the house, should be tested by being plugged at the lower end, and filled with water to ascertain if they are water-tight. In order to do this, the depth of the water at the upper end should be measured and observed to see if its level falls, in which case the drain should be examined for a leak. The drain should not be allowed to be covered in, until proved to be thoroughly water-tight.

Rain-water pipes.

The rain-water pipes may be divided into lengths with open heads at the top of each length, to receive where necessary waste-pipes from baths, lavatories, and sinks, and overflow-pipes from cisterns and water-closets. At its foot each rain-water or waste-pipe should open over or into a siphon gully, into which the waste-pipes from the basement sinks may also open by side inlets.

Siphon gullies.

Surface water should be carried off by the same siphon gullies, which are always efficiently trapped with water from the waste-pipes. The traps of siphon gullies used for surface water only are liable to be dry from evaporation of the water during dry weather, and may then give rise to a nuisance by the passage through them of air from the drain.

These siphon gullies should discharge by the branch drains before mentioned, into the inspection chambers or manholes.

Waste-pipes.

The waste-pipes from sinks, baths, and lavatories should be provided with cast lead siphon traps, and should be as short as possible. Whenever it is necessary to have a long waste-pipe, it should be ventilated by a pipe of its own diameter starting as near to the trap as possible, and carried up outside the house to a convenient point away from windows.

Grease trap for scullery sink.

With the scullery sink in large houses a special precaution is frequently necessary, on account of the large amount of greasy water and of sand discharged through its waste-pipe, and it is usual to fix a larger trap, called a grease trap, to collect the sand and fat and prevent them blocking up the drains.

This grease trap should be provided with a ventilating pipe, carried up to a convenient position, and may also be provided with an air-tight iron door for purposes of easy access. The scullery sink should, like other sinks, be provided with a siphon trap immediately under the sink, to prevent the entry of foul air from the grease trap into the house. The grease trap may advantageously be in the form of a flush-tank, which will discharge the water by siphon action when it is full, leaving the sand and grease behind in the tank.

Grease trap in form of a flush-tank.

Slop sinks.

Special sinks are sometimes provided for the discharge of bedroom slops. But they are not generally necessary or advisable, as such slops should be thrown down the water-closets, their seats being hinged so that they can be raised for this purpose, and also for the purpose of readily examining the apparatus.

SUPPLY OF WATER.

Regular supply necessary.

It must at once be premised that soil-pans and house drains cannot be kept in an efficient state of cleanliness by merely throwing slops and waste water down them. Some sort of regular supply of water is absolutely necessary. This supply may be given from a cistern or flushing-box, which supplies water to the closet only, placed in close proximity to the water-closet; or, again, the closet may be supplied, especially in country houses, from a rain-water cistern.

Self-acting apparatus.

In the East London Water Bills Report of 1867, Mr. James Simpson in his evidence says that self-acting water-closets are very economical as to the water; the self-acting apparatus being connected either with the seat or, more preferably, with the door of the closet: in the one case it is the weight of the individual which moves the contrivance causing the water to rush into the pan when he rises, and in the other the opening and shutting of the door. It is plain that with the latter plan waste cannot be entirely prevented, because if people choose they can prop the door open continually. These automatic arrangements are, however, very liable to get out of order.

Mr. Bateman was of opinion that the amount of water can be easily regulated by a "*waste preventer*," a contrivance limiting the amount of water that can run through the closet supply-pipe. Waste of water is generally due to improper apparatus. "Whenever the closet was supplied by a tap directly from the main, the waste was invariably enormous, from people leaving the tap open and the water running, from sheer carelessness;" and also under this plan, when the water in the service main has to be drawn off for repairs, the result has been, in Liverpool, that "a vacuum has been created, and the soil has been sucked back through the supply-pipe into the service main, and so carried on, and has contaminated the water of a whole district." This happened in cases where the service-pipe from the main was connected *directly with the soil-pan* of the water-closet.

Improper methods cause waste.

Connection of water-pipe directly with closet pan.

The dangers arising from water-closets deriving their supply of water from a pipe and tap direct from the main with a constant service, have been exemplified by the histories of several epidemics of enteric fever. The most important of these and the ones which have been most thoroughly investigated, are an epidemic at Sherborne in Dorset in 1873, reported on by Dr. Blaxall (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., 1874), an outbreak at Caius College, Cambridge, in 1874, the investigation of which, by Dr. Buchanan, appears in an Appendix to

Water-closets supplied with water direct from the main.

the same Report, and an epidemic at Croydon in 1875, also investigated by Dr. Buchanan. (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. VII., 1876.)

Enteric fever at Sherborne.

The cause of the epidemic at Sherborne was an intermission in the constant supply of water to the town, which caused foul air and probably also liquid filth containing the specific poison of enteric fever to be sucked up through those pipes, supplying water-closets directly from the main, in which the valves or taps had been left open.

Enteric fever at Caius College, Cambridge.

The outbreak at Caius College, which was almost entirely limited to the students of one particular court, was caused by sewer air and liquid filth being sucked into the water-main supplying this court, during an intermission in the constant service. Here the mischief was traced to one particular closet, to which not only was the water supplied by a pipe direct from the main, but there was also a branch or "weeping" pipe which opened over, and was intended to supply water to, the trap of the waste-pipe from the safe, this waste-pipe being connected to the soil-pipe beyond the siphon trap of the hopper closet. The soil-pipe was unventilated and in direct connection with the Cambridge Street sewer, also unventilated, and which contained, at this time, the evacuations of numerous enteric fever patients in the town. The specific poison of the fever, undoubtedly present in the air of the sewer and unventilated soil-pipe, must, as shown by Dr. Buchanan, have passed with the water in the trap of the waste-pipe of the safe, through the weeping-pipe into the water-main, when the intermission occurred, and the water-pipes and main were emptied by drawing off the water through the taps in the basement.

The epidemic of enteric fever at Croydon in 1875, which was very prevalent during the whole of that year, was considered by Dr. Buchanan to be, in large part, due to the entry of infected sewer air into the houses. He showed that the fever was also undoubtedly spread in many cases by contamination of the town water supplied by a constant service. This contamination was caused during the frequent intermissions in the service that took place, by the entry of foul matters into the water-mains from leaky drains and sewers laid in the same trenches with the mains, and also from the basins of water-closets, of which hundreds were stated to be supplied direct from the mains by taps, without the intervention of any cisterns. The contents of the water-closets, drains, and sewers, were liable to contain the infective material of enteric fever, throughout the whole of that year. Peculiar and offensive smells, accompanying the drawing off of water from taps, were frequently noticed in houses a short time before their invasion by the fever.

Enteric fever at Croydon.

There is very considerable danger in allowing water-mains and pipes to be laid in the same trench, or in close relation to house drains and sewers; as when the supply of water is cut off for any purpose, or even when water is flowing rapidly through the pipes, foul matters from leaky sewers and drains may be drawn by suctional force into the water-pipes, through imperfect joints.

Water-supply and sewerage systems must be kept apart

In the same way, when a pipe from a water-main is used to flush a sewer, the end of the pipe being merely guarded by a valve, sewage may be sucked through an imperfection in the valve during an intermission in the service of water.

Sewerage and water-pipes should be kept as far apart as possible, and no connection should be allowed between them.

Common plan of supplying closets with water.

The common plan for supplying closets with water is to place a spindle valve on a service box in a cistern, somewhere above them, the service box being provided with an air-pipe for the escape of air, when the valve, guarding the entrance into the pipe leading to the closet basin, is raised. This valve is worked by means of wires connected with the closet pull-up apparatus, which become stretched by use and have to be shortened from time to time. In this arrangement also there is obviously no provision against waste of water, for the water will run as long as the handle is held or fastened up, until the cistern is empty. Beyond this, there is however, the risk of foul air from the closet basin ascending the supply-pipe to the valve-box, and then passing through the air-pipe to contaminate the air over the water of the cistern, which may be, and generally is also, the cistern supplying drinking water.

Dangers and disadvantages of this plan.

"Regulator" valves.

To obviate these defects "Regulator" valves under the seat are used. With these, the supply-pipe from the cistern is always full of water down to the valve, unless the cistern itself is empty. By raising the handle the valve is opened, and the water allowed to flow into the basin of the closet. When the handle is put down, the regulator prevents the valve being closed at once, and so water continues to flow for a time through the valve, while it is gradually closing, into the basin. This is called the "after-flush." Even with this arrangement, however, water-closets should be supplied from a separate cistern, or else by means of an intercepting cistern, or of a water-waste preventer. By an intercepting cistern is meant a cistern not supplied from the main water-pipe or "rising

"After-flush" provided.

Intercepting cistern.

main," but from the main water cistern, thus preventing direct communication between the latter and the closet basin.

Water-waste preventers.

Water-waste preventing cisterns are constructed to hold only two or three gallons of water, which quantity is discharged into the closet basin, when the handle, or it may be the chain, is pulled to start their action; and as long as the handle or chain is retained in this position, no more water will leave them. It will be seen that these contrivances, besides preventing waste of water, are interposed and prevent direct connection between the water-closet and the drinking water in the cistern or main water-pipe.

A simple form.

One of the simplest forms of water-waste preventers has its supply-pipe to the closet merely guarded by a spindle valve, which can be raised by a lever worked by a chain and ring. When the chain is pulled, the spindle valve is raised, the water being discharged, while at the same time the ball valve is also raised by the lever, and continues raised, preventing the entry of any more water into the waste-preventer, as long as the chain is held.

Siphon action water-waste preventer.

In another variety of waste-preventing cisterns, the water is discharged by the action of a siphon, which is started when the handle or chain is pulled. In these cisterns, no more water can be discharged until they are again filled, and a very short pull is sufficient to start the siphon, when the whole contents of the cistern will be discharged. In the waste-preventing cistern first described, the chain or handle must be held until the cistern is empty.

Supply by large cisterns.

Mr. (now Sir Robert) Rawlinson suggested that in the poor districts of towns, fifty or one hundred gallon cisterns should be constructed, a pipe passing from such a cistern to the inside of several houses, and each tenant being allowed to take as much as he wants.*

The constant system of water supply is agreed on all hands to be infinitely superior to the intermittent, as the necessity for cisterns is thus almost entirely dispensed with. The waste alleged as a fault of that system is to a great extent, if not entirely, prevented by the taps being placed in the interior of houses instead of outside them, and the pipes which supply the water-closets may be provided with a small service box into which water flows.

Service-box for water-closets.

But, after all, the great cause of waste is want of supervision. "A system of water supply, whether intermittent or constant, necessitates a constant and careful supervision." *

Supervision.

Among the disadvantages of the constant system, it is stated that in Salisbury the supply sometimes runs short in the highest parts of the town while it is being wasted in the lower parts. But here in the poor tenements there is no self-closing apparatus, water-waste preventers having been tried, but abandoned, because it was found that they froze in winter.

Supply may run short in higher parts of towns.

At Penrith, houses in the poorer parts of the town had outside taps which were found to conduce greatly to waste. They have since for the most part been changed for inside ones.

Outside taps.

It is obvious that when taps are over the floor in the interior of houses the water cannot be left running without serious inconvenience to the inhabitants, and such carelessness is less likely to occur.

Advantages of the constant system.

The advantages, then, of a constant service at high pressure are—that the water is always fresh from the

* East London Water Bills Report, 1867.

main, and that the pollution of it in cisterns is avoided —this last advantage being exceedingly great in the poorer classes of houses, where the cisterns are continually allowed to get into an exceedingly filthy state; that there is always a supply of water; and that the mains are charged in case of fire.

The disadvantages are—the leakage of the fittings and the weakness of the lead pipes (that is to say, of the lead pipes originally laid for the intermittent system); the fact that the increased consumption of water in the early part of the day requires an increased pumping power; and the points that have been already alluded to, namely, that the waste at low levels reduces the pressure in the mains to such an extent that the higher levels cease to be supplied, and that during the repair of the mains the whole district would have to be deprived of water for a time, that is to say, would have to be placed on the intermittent system.

Disadvantages.

As regards the strength of lead service pipes suitable for an intermittent not being sufficient for a constant service, the Rivers Pollution Commissioners have shown that there is probably a greater maximum of strain on the pipes with an intermittent service than with a constant, the suddenness with which the water is turned off or on, in the former system, by the use of the common stopcock, causing a greater strain on the pipes than when the water is drawn or shut off by the screw down tap used with the latter system. (*Sixth Report R. P. C.*, p. 230.)

Greater strain on pipes with the intermittent than with the constant service.

The remaining objections have been overcome in those towns where the constant system has been adopted, by proper supervision, by inspection of fitings, and by control of waste.

On the intermittent system the water must be kept in cisterns, and, where cisterns are not supplied, as in many of the poor districts of towns, in tubs, butts, and so forth, in which it becomes foul and unfit to drink.

Waste less with constant system.

The Royal Commissioners on Water Supply (from whose Report this information is chiefly derived) found that the waste of water is much less under the constant system, although the actual use of it is greater.

Additional advantages.

But these are not the only advantages. The water is purer and fresher, and at a lower temperature in summer, and it is less subject to frost in winter; and as to the disadvantages, the inconvenience from interruption during repairs is never actually experienced, as the interruption need only be for a few hours in any case. On the other hand, the interruptions from neglect of turncocks, limitation of quantity, leaky taps and cisterns, and so forth, are absent in the constant system.

Economy in pipes and cisterns.

The economy in pipes, etc. is obviously great. The pipes are smaller and are made much stronger, so that practically there is less bursting, while cisterns are not necessary, except for water-closets and to supply boilers. Where cisterns already exist, however, they have often been retained on the constant system.

From the Report on the East London Water Bills, we find that where the intermittent supply has been changed to the constant, there has been an enormous waste of water, chiefly from carelessness.

Precaution during frost.

It is recommended that in frosty weather the water should be turned off from the house by the turncock, and that the water actually in the pipes should be run away from the lowest tap (water-pipes do not often freeze underground);

Position of taps.

and that the taps should be placed so that the water cannot run away to waste without producing inconvenience, and that for water-closets special arrangement must be made so that the water cannot run continually. Mr. Hawkesley says that "it is a question of the size of the pipes," and that when a constant supply is well managed the waste is less.

Inspection, however, is always necessary.

Result of inspection.

It is stated that at Norwich the consumption has descended from 40 gallons a head to 15, since the fittings have been inspected.

Contamination by cisterns.

The Commissioners are of opinion that "the use of cisterns for the purpose of storing water for consumption is probably a more fertile cause of impurity than any pollution of the river from which the water is drawn;" and Mr. Rawlinson remarks that "the water that the poor people get is contaminated so far as water can be contaminated." (*Loc. cit.* qu. 3695.)

Storage in cisterns.

Water stored in cisterns not only becomes contaminated, by the dirty state in which cisterns are often allowed to be, especially where uncovered and exposed to the outer air of towns, or placed in improper positions, as under floors or in water-closets, but also by the unfortunately prevalent custom of directly connecting the overflow or standing waste-pipe of the cistern with the drain or soil-pipe. If connected with the drain, an S bend is occasionally found on the pipe, and if with the soil-pipe, the connection is usually made with the D trap under a water-closet.

Overflow-pipe connected with the drain.

In either case, the resulting evils will be alike; the water in the S bend, even when there is one, evaporates, from want of renewal; if there is not one, air from the drain passes unchecked up the overflow-pipe, to contaminate the air over the cistern and be absorbed by the water, causing thereby a very danger-

Causes a very dangerous pollution of the water in the cistern.

ous pollution. The foul gases generated in D traps will also, by this means, find their way into the drinking water. Foul-smelling water in a house is usually caused in this way, and the evil effects produced by drinking such water are often most insidious and deadly. This is indeed the chief cause of the spread of typhoid fever in London and many other large towns.

The Health of Towns Commissioners considered the question of a constant water supply very fully, and showed that if it were adopted—

Cost of constant supply.

> The use of water-butts and water-tanks may be entirely dispensed with, and water may be distributed into every room fresh from the general reservoir or filter, at an expense not exceeding 1½d. a week; that for the cesspool, a cleansing apparatus, or soil-pan with water, of the nature of a water-closet, and the requisite drains, may be substituted at an expense of not more than 1½d. a week, and all refuse be instantly removed in water through impermeable pipes; so that the foundation of the house need not be saturated with decomposing matter, and none need remain on the premises to give off effluvia. (*First Report*, vol. i. p. 109.)

It is there stated that the Trent Water Company has always maintained the supply constant by night and day—

Less expensive to company;

> Except during a period of one month, when for the purpose of experiment the water was shut off at ten in the evening, and turned on again at five in the morning. It was then ascertained that it would be less expensive to pump water than to maintain an extra establishment of servants and workmen to open, shut, and repair the valves, to draw the fire-plugs for the more frequent cleansing of the pipes, to attend to complaints of deficiency and inconvenience, and to make the inspections necessary to prevent advantage being taken of the absence of the water to attach communication pipes without the Company's consent or knowledge. (*First Report*, vol. i. p. 327.)

to tenants.

They also came to the conclusion, that by the arrangement of keeping the pipes constantly full, dispensing with the necessity of tanks, ballcocks, branch pipes, and so forth, more than half the tenant's expenses, and more than one-third of the total expense of introducing water into houses, were got rid of.

In the Sixth Report of the Rivers Pollution Commissioners (pp. 232, 233) is given a table showing the amounts of the daily water supply in seventy-two towns on the constant system, and in twenty-four on the intermittent system. From this we learn that the average daily supply per house on the constant system is 134½ gallons, although in these towns there are numerous factories, where a large quantity of water is consumed. In the twenty-four towns, with an intermittent service, the supply per house is 127 gallons daily, although in these towns there are far fewer factories proportionally; whilst in London the supply per house is 204 gallons daily. Less water supplied with a constant service.

The charge of excessive waste brought against the constant system of water supply is entirely negatived by the foregoing figures. Meters are now made for registering the waste by leakage from mains. (See *Journal of Society of Arts*, May 1882.) Waste-water meters.

From the same Report (p. 233) we find that "5079 houses in Lincoln, a city which, being set upon the side and summit of a hill, presents great variations of level, are sufficiently supplied with 260,000 gallons daily on the constant method, the inspector having power, not only to examine all the fittings throughout his district, but to repair them, after due notice, at the expense of the tenant; while at Oxford, half the population of the city, corresponding to about 5500 houses, use 1,200,000 gallons daily, although the whole supply is shut off during the night-time. This is a quantity corresponding to nearly five times the supply per house that is found sufficient at Lincoln." Water-supply at Lincoln. At Oxford.

CAUSES OF FAILURE OF WATER-CLOSETS.

It is plain that water-closets are no more likely to be free from nuisance than any of the other contrivances before described, if they are not properly taken care of. Their very principle requires that they should be supplied with sufficient water, at a sufficient flushing power; and it is universally acknowledged to be advisable that in closets frequented by great numbers of people, as in schools, railway stations, hospitals, and so forth, the method of supplying the water to the basin should be self-acting, or there should be proper supervision by an official appointed for the purpose. Wherever water-closets have been found a nuisance, these conditions have invariably been flagrantly violated; thus, in Hull, it was found that water-closets, when used by several families, were objected to as being "everlastingly a nuisance."

Conditions necessary.

In Nottingham the water-closet fails in the poor quarters, and, as we have already seen, pail closets have been substituted for it; the reason of this is that, as in all other such cases, there has been a want of any sort of supervision, and moreover a wrong kind of closet.

Violations of them.

At Edinburgh, where pail closets are so much used, water-closets were tried in the lodging-houses, but were found to be much befouled. When limited to one, two, or three families, and kept locked, they worked satisfactorily.

The same effects were experienced at Glasgow.

In the poor parts of all towns, water-closets, especially when frequented by several families, will be found to fail unless they are, at any rate to a slight extent, under the control of an authoritative supervision. It is not fair to compare water-closets which have not been placed under any pretence of supervision with other forms of closet which have been minutely and constantly looked after by appointed persons.

Unfair comparisons.

In Dr. Buchanan's Report on the working of the earth closet system, it is stated that at Lancaster Grammar School the water-closets always got out of order, from things being put into them and from the apparatus being broken, showing that the apparatus itself was not of that simple and self-acting character which we have already insisted on as being necessary in all large establishments.*

Forms unsuitable for careless people.

The more complicated forms of water-closet are obviously quite unsuited for careless and wantonly mischievous people. The basins get broken, and the traps choked up, or the water runs continually from the cistern through leaky valves; in frosty weather the water supply is stopped and the consequence is that the closets become filthy and stinking, and are cleaned out only once in several days; while closets which are well cared for, even in the same quarters, and which are not frequented by too many families, are found in good condition without waste of water, and very rarely injured by frost.

Merely requires ordinary care.

In Carlisle, "water-closets are universal and kept in good order, Macfarlane's especially being found admirably suited to the wants of poor neighbourhoods." (*Ninth Report M. O. P. C.*, p. 108.)

* The water-closets still left, "which have all their apparatus broken, are now cleaned by buckets, and are found free from smell." (*Twelfth Report M. O. P. C.*, p. 83.)

SIMPLER FORMS OF WATER-CLOSET—COSTS.

The First Report, already referred to, of the Health of Towns Commission, has afforded us some very valuable evidence with regard to the possibility of constructing water-closets at a sufficiently cheap rate in poor neighbourhoods, and several simple forms of apparatus are described in this Report.

Cheap plans.

A pan with a perpendicular pipe leading into the drain, through which the waste water from the house and roof would flow, would be sufficient. The present necessaries might be converted into such water-closets at an expense of £5 or £6 each, and the tenants would very gladly pay a small additional rent to be free from the annoyance and injury the present arrangement produces; while the landlords would find it their interest to incur some expense to avoid the injury which their property now suffers from liquid filtering through to the foundations of the houses. (*First Report*, vol. i. p. 212.)

Increase of value of property.

This would seem to be rather a high estimate, as the calculation for erecting a cheap water-closet in Ashton-under-Lyne gives it at £1 : 13 : 5 for a closet on the ground floor, and an additional charge of 12s. for fitting up one on the chamber story. This includes a strong fire-clay water-closet basin, with a proper fitting socket joint; a strong fire-clay S shaped soil-trap, 4 yards of fire-clay soil-pipe, all to be glazed and smooth inside; 5 yards of ½-inch patent lead service-pipe; one water tap, and all the necessary fittings. The remark is made that the "fire-clay pipes mentioned above are ¾-inch in thickness, exceedingly strong in texture, and by no means brittle like earthenware." (*First Report*, vol. i. pp. 306, 307.)

Construction and cost.

Materials

In the second volume of this Report there are some plates with descriptions of very simple forms of closets, consisting of a soil-pan and a siphon pipe or simple trap placed at the junction of this with the house drain. The soil-pipe is made of cast-iron, the disadvantage of which is that it corrodes after a time, and the filth is then apt to adhere to it; or of earthenware, which answers the purpose better. The seat of the closet is slung on hinges to a wooden frame, so that it may be lifted and vessels emptied into the soil-pan without wetting or dirtying the seat. The expense of this apparatus is stated to be from 25s. to 30s., including the price of fixing. This is supposing that a great number were required. If a water-pipe and tap were added, it would perhaps cost about 15s. more. (*First Report*, vol. ii. pp. 315, 316.)

Again: Mr. Thorp gave evidence that he had constructed water-closets for the Hull gaol, with an iron soil-pan of about 10 inches in diameter and a pipe of 5 inches, the pan and pipe being joined together by a bell end, run in with lead, and the pipe being S shaped. He says that "if numbers were made they might be made at low prices, less than £1 each," and that "this same kind of closet made of earthenware may be fixed at about 8s. each." He adds— Very cheap form.

It is quite sufficient to prevent any smell coming into the room from the drain, and it passes the soil and everything well, although there is no regular supply of water, and only such water is used as may be put in from time to time, the soil-pan being in fact used as a sink. But it would be a proper improvement to have regular supplies of water, and then the apparatus would work completely. (*First Report*, vol. ii. p. 333.) Soil-pan used as sink.

Its cost adds 1¼d. to the weekly rental, or 2¼d. including cost of water (Nottingham): "less than half the existing charge of the present noxious system" (p. 319).

In the East London Water Bills Report it is stated that the cost of a pan and siphon trap was 38s. with 6s. or 7s. for fixing, but that if the pan already existed Other estimates.

the cost was only 37s. altogether. The double valve cistern is stated to be the cheaper plan.

In Liverpool every siphon water-closet ordered costs £3 : 10s. (*Twelfth Report M. O. P. C.*, Appendix, p. 120.)

Costs at the present time.

At the present time (1886), the cost of a short stoneware hopper closet or artisan closet with flushing rim and siphon trap is 5s. 3d.

A galvanised sheet-iron water-waste preventer, with ring and chain pulling up the ball valve, and so shutting off the supply of water by the same action which opens the supply valve to the closet costs 9s. 6d. To these items, the cost of fixing must be added.

The cost of a stoneware trough closet for three persons is £2 : 7 : 6 ; beyond this number 14s. extra per person, and the siphon trap is 10s. extra.

The price of a 12-gallon stoneware siphon flush-tank is £1 : 10s.

Four-inch glazed stoneware drain-pipes with spigot ends are priced at 6d. per foot. Six-inch pipes are 8d. per foot.

The price of a 4-inch stoneware disconnecting trap is 6s. 6d. ; that of a siphon gully with 4-inch outlet is 3s. 6d., with side inlet 6d. extra.

The average price of lead soil-pipes, 7 lbs. to the foot, is 3s. per foot.

TROUGH AND TUMBLER WATER-CLOSETS.

The more complicated forms of water-closet being entirely unsuited for use by careless persons, especially in the poorer neighbourhoods of large towns, from the too complex nature of the contrivances for flushing the basin, and their easy accidental and wilful destruction, and also on the other hand from the entire want of all authoritative supervision, several devices have been proposed by which the water-closet system can be successfully introduced into such neighbourhoods.

Plans for poor neighbourhoods.

To several of these contrivances we have already alluded in the simpler forms of the ordinary water-closet, but to some others which seem especially suited for collections of persons in alleys, courts, and in large institutions such as factories and schools, a special allusion must be made.

What are called trough water-closets have been erected in Liverpool, West Derby, Warrington (one as a trial), and perhaps other towns; they may be briefly described as follows (see *Twelfth Report M. O. P. C.*, Appendix, p. 120) :—

A long trough is placed below and behind the seats of a series of closets. At the one end is a communication with a drain leading into the sewer. This opening is closed by a plug connected with an iron rod, by which it can be raised or lowered into the drain mouth by the scavenger. Behind the back wall of the water-closet is a small chamber to which the scavenger only has access, and it is from this chamber alone that the plug can be interfered with. The scavenger comes daily, lifts up the plug, lets the contents of the inclined trough run into the sewer, washes out the trough with hose which is placed in the chamber for the purpose and which is connected with a hydrant, sweeps it clean, charges the trough with water, lets down the plug into the drain mouth, and leaves it for twenty-four hours. The closets themselves are cleaned by the users in rotation, and an inspector calls every two or three days to see that it is done. If it is not done properly the offenders are summoned, and some have been sent

Trough closets.

Scavenger' duty.

Penalty for not keeping closet clean.

to prison for the offence. The ashes and other refuse are put into the street and carted away daily by the scavengers.

Favourable opinion.

Dr. Buchanan and Mr. Radcliffe say of these closets :—" Nothing could be more admirable than the working of the Liverpool arrangement, and nothing could be more marked than the difference between them and what are called water-closets in the poor neighbourhoods of London and other large towns."*

Five years later, writing of the trough closet, Mr. Radcliffe says,

Favourable opinion confirmed by experience.

The Liverpool trough closet was described in the Report for 1869 as admirable in arrangement and working. The five years' additional experience of its operation confirms in every respect the opinion then formed of its perfect adaptability to the wants of a poor population. The closets are cleansed daily by the people using them, according to a systematic rota ; there is no waste of water, no injury from frost, and the whole of the machinery is worked regularly by the public scavenger. In addition to these advantages the wear and tear, owing to efficient original construction, has been remarkably small. (Report by Mr. Radcliffe, Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., p. 157.)

In their Report on the Sanitary State of Liverpool, 1871, Drs. Parkes and Sanderson express their opinion on the trough closets which were in use in many of the courts which they examined (pp. 69-71).

Trough closets in courts of Liverpool.

As an apparatus for the speedy and safe discharge of large quantities of excreta into a drain, we regard the trough closet as superior to any other with which we are acquainted. So long as the trough is full of water, the solid matters which fall into it are completely covered, and are flooded away into the sewer at the moment that the trough is discharged, as we ascertained by personal observation, in the most efficient and complete manner. Obstructive objects of an improper kind, introduced by carelessness or by mischievous design, are easily removed by the scavengers in charge, so that blockage of court drains is an uncommon occurrence. The troughs are of extremely simple construction, not easily deranged, and can be worked at a comparatively small expense ; for all which reasons they are better adapted for a population such as that of the Liverpool courts than any other form of water latrine.

* See Twelfth Report M. O. P. C., Appendix, p. 139.

The woodwork and seats were, however, found in a state of "disgusting filthiness," due to the fact that many of the adults, both male and female, habitually stand on the seat when using the closet. It appears that this habit has arisen from fear of infection.

Seats filthy.

The effect on the house drains of the process of discharging the troughs was also determined. For this purpose some of the drains in the courts were opened. It was seen that "though during discharge the flow was rapid, the quantity flowing at any moment was never sufficient to fill the drain-pipe, so that it could not act as a piston." In the cellars, when the traps were in order, it could not be detected that "any air was forced back through the traps when the trough closet was emptied. In those cellars where the traps were deficient or ineffective, the emptying of the trough closet caused an inconsiderable draught, which was chiefly from the cellar into the drain. In some cases it was at times reversed, but the inflow seemed always greater than the outflow."

Effect on house drains of discharge of trough.

An additional advantage which Drs. Parkes and Sanderson considered the trough closet to possess is that "in the presence of an epidemic, either of enteric fever or cholera in a court, it will be easy to put disinfectants into the trough water-closets, and thus to destroy the noxious power of the discharges before they enter the sewers."

Prevention of epidemics.

Another contrivance of a similar sort, but entirely self-acting, known as the "Tumbler" closet, has been introduced into Leeds, Birkenhead, and Tranmere. In this there is also a trough running under the privy seats and made of stoneware; the water trickles into a swinging basin at the upper end, which is so

Tumbler closet.

Quantity of water.

constructed that it capsizes when full and washes out the contents of the trough into the drain; it can be arranged so as to capsize at any interval that may be thought advisable. "For a tumbler closet 1½ gallon, and for the ordinary siphon or pan (hopper) closet 2 gallons a head per twenty-four hours," are required. These closets are found to keep very clean, "to require fewer repairs and less attention than the siphon or pan (hopper) closets," and to be unaffected by frost.*

Failure of the tumbler closet.

The tumbler closet, which has been to a small extent in use at Birkenhead for a considerable number of years, has proved somewhat of a failure, not from any fault of its own, but from misconception of its powers by private persons, leading to radical faults in its construction, and by the absence of proper supervision on the part of the local authority, who also "permitted the regulation of the water supply to be governed by considerations of economy, not always consistent with the sanitary object for which the closet was constructed." Thus Mr. Francis Vacher, Medical Officer of Health for Birkenhead, in a report on the tumbler water-closet system in that town, given in Mr. Radcliffe's report before mentioned (Appendix to *Report M. O. P. C.* and *L. G. B.*, No. II., pp. 209-214), says:—"The tumbler closet appears to me to be so perfect in theory that I regret I am unable to give a more satisfactory report of my experience of it." The evidence upon which the report is based is furnished by only twenty-two such closets. "As these all, with a single exception, not unfrequently get out of gear or become obstructed and cause nuisances, I cannot resist the conclusion that tumbler closets are not suitable, at all events, for the class of tenants for whom

Perfect in theory.

* First Report R. P. C., 1868, vol. ii. p. 251.

they have been provided in Birkenhead." He attributes the failure of the system chiefly to the ranges having been, for the most part, ill-planned, too long, and required to serve too many persons. Thus the mean length per range was 54 feet; the average number of seats each range received from being 6·9, the average number of houses served per range being 8·6, and the average number of persons to a range being 43. In the case of one closet the tumbler of a capacity of about 18 gallons was designed to flush beneath 32 seats, accommodating 37 houses, the distance from mouth of tip to end seat being 119 feet, and the population of the houses served being about 190 adults and children. "The folly of building a range such as this it cannot be necessary to insist upon." The majority of the tumblers derived their water supply straight from the main, without the intervention of cisterns, the result being that for two days a week, when the water was regularly turned off, the closets were not flushed at all. The rates of tipping of the tumblers were found to be very unequal, varying from every twenty minutes to every six hours or less frequently, and at some schools, where the water was measured by meter and paid for by quantity, the supply of water to the tumbler was stopped altogether, except once a day, when it was allowed to discharge two or three times in succession.

Ranges ill-planned.

Rates of tipping of the tumblers very unequal.

Mr. Vacher makes the following suggestions regarding the structure and management of tumbler closets:—

Mr. Vacher's suggestions.

1. The tumbler of iron, cast in one piece, and to hold a charge of not less than 18 gallons, should be swung in a strong wooden frame set in brickwork, the trunnion caps being furnished with oil holes and pegs, the whole being in a locked compartment, accessible only to the sanitary authority's accredited servant.

2. The channel to be flushed should be a brickwork, cement-lined, open, straight trough, round bottomed, with slight incline, and made to retain water, at least 1 inch, at its shallow end. It should terminate in a siphon trap protected by a grid, and should not measure more than 25 feet, or receive from more than 5 seats.

3. The seats should be of wood, not painted, each in a separate locked compartment, each exclusively for the use of the occupiers of one house, and accessible only to the occupiers of one house and the sanitary authority's accredited servant.

4. The water supply should be by cistern, the capacity of each cistern not being less than 1000 gallons, except in districts where the mains are always charged, and the service-pipe should be fitted with a ferule of a size to enable it to deliver not less than 18 gallons every forty minutes.

5. Inspection should be undertaken by the sanitary authority, and should be systematic, thorough, and frequent, every tumbler, channel, seat, and cistern in a district being examined by a servant of the sanitary authority at least once a week.

Trough should be flushed by a siphon-action flush-tank.

By the above account is shown the necessity of some self-acting arrangement, by which a large body of water shall be periodically discharged into the trough. Such an arrangement is provided by a siphon-action flushing-tank, which empties itself automatically at regular intervals, and which can have its discharge regulated according to the necessities of the case. These tanks have no moving parts, are not liable to get out of order, and require little or no attention; they are therefore in many respects better than tumbling boxes (see p. 128).

Conditions to ensure perfect success.

By these simple contrivances it is found that the water-closet system may be managed so as to be "entirely applicable to the circumstances of the most ignorant and most careless population;" the only necessary addition being that, as in any other arrangements, the management be entirely undertaken by the scavengers of the sanitary authority.

"Where these conditions are observed as thoroughly as they are observed in parts of Liverpool, we believe that water-closets are the best means of removing excremental matters from the poor neighbourhoods of a town."*

It will be at once observed that in each of these cases the scavenging arrangements need not be anything like so complicated as they must necessarily be with any of the other systems that we have already considered. There is no removal or carting away of the excremental matters in any form, the scavenger has merely to visit the place to see that all is going on right, and in the case of the trough closets without siphon-action tanks, to empty the contents of the trough down the drain. The ashes of course have to be collected separately, just as in all other parts of the town.

No carting necessary, except for ashes.

In the various Reports on this subject, one continually meets with the statement that in a certain town there are only a few water-closets, and these always in the best houses. From this we see that the persons who are best off, and who are, as a rule, cleanest in their habits, have invariably adopted the water-closet system in preference to any of the older ones. It is found, when properly managed, as every one very well knows, to be in no way a nuisance; on the contrary, by it all the excremental matters, together with all the slops and liquid house refuse, are immediately carried away, out of and far from the house and the neighbourhood, and by a simple disconnecting trap, the entrance of foul gases from the sewer into the house is, to all intents and purposes, entirely prevented. If, then, the lower classes of people do not manage water-closets as they should be managed, it is plainly not the fault of the system, but the want of a due regard to cleanliness on the part of the users; and until they can be taught to manage

Water-closet always adopted by clean people.

Reasons.

* Twelfth Report M. O. P. C., Appendix, p. 140.

them themselves, the only way to get out of the difficulty is to have them managed for them.

What we have wished to point out is, that instead of destroying the water-closet system, as introduced into the neighbourhoods to which we have just referred, it may undoubtedly be made to answer perfectly every sanitary requirement by a tithe of the supervision and incomparably less scavenging work than is universally acknowledged to be absolutely necessary in all other forms of excremental removal.

Necessity of supervision, but of much less than with any other system.

In fact, we must agree with Dr. Syson, who said before the Rivers Pollution Commissioners, "where a water-closet is mechanically perfect, I look upon it that it is perfect in theory; but I find from experience that water-closets, and the drains connected with them, are laid out so badly, that they themselves are apt to become a source of annoyance and discomfort." (*First Report R. P. C.*, 1868, vol. ii. p. 189.)

True reasons of failure, when it occurs.

So that it is not the fact of their being water-closets, but the fact of their being badly constructed or not looked after, that makes them a nuisance wherever they are so.

The great improvement in the sanitary condition of towns into which the water-closet system has been introduced will be described in another place.

CHAPTER VI

SEWERAGE

THE original idea of a sewer was that it was a large drain to carry off the rain-fall and subsoil water of a town, and it was only secondary considerations that pointed out the convenience of making this drain a receptacle for liquid refuse matters also. That the Cloaca Maxima of Rome was built with the first-named intention, we see from the account of it given by Livy: *—"Et infima urbis loca circum Forum, aliasque interjectas collibus convalles, quia ex planis locis haud facile evehebant aquas, cloacis e fastigio in Tiberim ductis siccat;" but that it was used for the secondary purpose which we have just mentioned, and with which we have especially and indeed almost exclusively to do, we see from the statement:—"Cloacamque maximam receptaculum omnium purgamentorum urbis, sub terram agendam." † Smaller sewers were made which either opened directly into the Tiber or into the Cloaca Maxima itself, and which "ramified through all Rome." ‡ Pliny calls these *cloacæ* "operum omnium dictu maximum." §

Original idea of a sewer.

Secondary one.

From the time when Tarquinius commenced this grand work down to the present day, it has been found

* Livy, i. 38. † Livy, i. 56. ‡ Smith's Ancient History, vol. ii. p. 193. § Pliny, Hist. Nat. xxxvi. c. 15, s. 24.

necessary to provide sewers for towns, no matter in what way the actual excrementitious matters are dealt with, and as a general rule they have been built more or less on the Roman plan. This we do not wonder at, since the durability of these works is shown in the fact that the great prototype which we have above mentioned has lasted almost entirely unhurt for twenty-four centuries, and still continues to perform its original functions of *drain-sewer*. The city which at present exemplifies in the most complete manner an enlarged and improved form of this system is perhaps Paris, underneath the principal streets of which not merely sewers but subways are constructed, with the tributary mains named and the house-pipes numbered. The London main sewers vary from 4 feet in diameter to 9 feet 6 inches by 12 feet in some cases; the three northern outfall sewers are each 9 feet by 9 feet (with vertical sides), the southern outfall sewer 11 feet 6 inches in diameter. Such an enormous size as this is found requisite not for the actual amount of foul water which generally does pass down the sewers, but, as Parent Duchatelet points out, for that which it is *possible* that the sewer may be required to contain under certain circumstances, especially during heavy rains. Neither the existence of such sewers nor their size in any way depends upon the amount of excrementitious matter that is received into them. The sewers we have mentioned were all constructed for towns in which the solid part of the excrement and a certain proportion of the liquid were carefully kept away from them, that being considered to be the part most valuable as manure. In Paris this is especially the case, as we have already pointed out, by the general prevalence of the system of *fosses permanentes* and *fosses mobiles*. In London, too,

Cloaca Maxima the type.

Immense size of drain sewers.

Reason for it.

Excrement kept out of them.

this was the case when the privy system was in vogue, and of other towns the same remark may be made.

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. (Bazalgette, *Main Drainage of London*, p. 5.)

In Rome, certainly, the greater part of the excrementitious matters were collected in enormous underground pits, which have been lately discovered by Mr. Parker, so that in no case were these sewers constructed for the removal of excrementitious matter. It does not by any means follow from this that the water they conveyed was to any notable extent less impure or less offensive than the contents of sewers into which the whole of the refuse matter of all sorts is received. This was perfectly well pointed out by Parent Duchatelet, in his remarkable memoir on the sewers of Paris, published in 1836. He there considers that the identity between the sewers and the *fosses* has been completely proved, and he rightly argues that sewers, even under the conditions found in Paris, require to be constructed with the same precautions as the *fosses* themselves; in fact, any one who has examined the sewers of Paris, Lyons, or any other town where the cesspool system is as efficiently and thoroughly carried out as it can be, knows perfectly well that the sewage is just as foul, just as offensive in every way, as it is in the most thoroughly water-closeted town. But we have had some important evidence on this point, in the First Report of the Rivers Pollution Commissioners. It is there shown that there is "a remarkable similarity of

But contents still foul.

Same rules as for cesspools.

Recent confirmation of this point.

composition between the sewage of midden towns and that of water-closet towns. The proportion of putrescible organic matter in solution in the former is but slightly less than in the latter; whilst the organic matter in suspension is somewhat greater in midden than in water-closet sewage. For agricultural purposes, 10 tons of average water-closet sewage may, in round numbers, be taken to be equal to 12 tons of average privy sewage." It is also shown that more persons contribute to a given volume of sewage in midden towns than in water-closet towns, because it is found that the proportion of chlorine is greater in the sewage of the former towns than in that of the latter, and the cause of this difference "is obviously to be sought for in the somewhat increased quantity of water needed by and supplied to" the water-closet towns. (*First Report R. P. C.*, 1868, vol. i. p. 29.)

Water-closet sewage *v.* privy sewage.

Latter so rich because less water with it.

The Committee of the Local Government Board on Modes of Treating Town Sewage were of opinion (Report 1876, p. 59) that "the entire excreta of a town population added to the waste water is, by volume, only about as 1 to 100; consequently the capacity of the sewers need not be enlarged, nor need steam pumping power (if required) be increased." That is to say, that sewers originally intended to convey away waste waters only, need not be enlarged when it is intended that they shall also receive the excretal refuse of the population.

Excretal refuse only slightly increases the volume of sewage.

We must remark, however, that although there can be no doubt as to the truth of the general fact above stated, yet it may be questioned whether the similarity between these two sorts of sewage is as great as is here indicated. It would not appear that the samples, of which the analyses above referred to were made, were really average samples, that is to say, procured by taking samples at frequent intervals during a period of twenty-four hours, and mixing them *in the proportion indicated by gauging at the time each sample was taken,* a source of error pointed out to us by Mr. Thornhill Harrison. However, the exact results may be ascertained by future researches; what cannot be denied is "that the very large collection of feeble manure from the several towns . . . does really very little to save the rivers. . . . Bolton receives its river water virtually clean, and hands it on in an extremely foul and offensive condition. Rochdale fouls the Roch and Spodden, and Bury makes a most obvious addition to the filth of both the Roch and Irwell passing by it. Over Darwen adds most offensively to the pollution of its stream, and the Blakewater is entirely converted into sewage by the town of Blackburn. The Irwell and Irk and Medlock come down already very foul, but the quantity of filth they bring is enormously increased as they pass through Manchester and Salford" (p. 36); and from their researches these Commissioners were led to conclude that "retention of the solid excrement in middens is not therefore attended with any considerable diminution in the strength of the sewage, although the volume, even in manufacturing towns, is somewhat reduced; neither is the case substantially different where earth closets are substituted for the Lancashire midden, for the sewage from Broadmoor Lunatic Asylum, in which these closets are partially used, exhibits no exceptional degree of weakness. . . . It seems hopeless therefore to anticipate any substantial reduction of sewage pollution by dealing with solid excrementitious matters only" (p. 30). Thus, then,

Average samples.

Rivers fouled in any case.

Useless to deal with solid excreta alone.

Drains act as sewers under any system.

we see that in every case the sewers not only act as drains, but remove an immense quantity of refuse matter, and that therefore Parent Duchatelet's conclusion, that they must be considered as elongated cesspools, was a correct one. We have seen how it is necessary to construct cesspools; that the one great condition is that they should be impervious, in order that their contents may not soak through into the surrounding soil, poisoning the wells and giving off foul emanations into the air. This, therefore, is a conclusion which has also been come to in the case of sewers: they must be made *impervious*, and to this end, in Paris, following up the recommendations of the renowned hygienist whose name we have just mentioned, they are lined throughout with impervious cement; and even as a recommendation for ordinary brick sewers, one witness before the Health of Towns Commission stated that when *properly constructed*, and with good stone-lime and river-sand cement, they become water-tight after a time. But here we stumble upon a dilemma: we have pointed out that the original object of the sewers was to carry off the rain and subsoil waters, that is to say, to act as drains. Now drains, in order to be efficient, must be pervious, must allow the subsoil water to get into them as easily as possible. "A drain," says Mr. Bailey Denton, "is intended to draw out of the land through which it passes the wetness that is in it, and to exhaust that wetness as far as capillary attraction and natural retentiveness will permit" (Letter to the *Times*, 28th October 1869). But now we find that, through the introduction into them of refuse matter of towns, in all cases it is decidedly advisable to have them impervious; in fact, we require to make them pervious

Must be impervious.

What a drain is.

and impervious at the same time,—an obvious impossibility. But it may be alleged that as a general rule there will be no risk of the foul water percolating through the sewers into the surrounding soil. It is perfectly true that where the incline is sufficient and the sewers well constructed and without any chance of obstruction, there will certainly not be any great risk of this taking place; but where the ground is flat, so that sufficient incline cannot well be given to the sewers—as is the case in Paris for the most part —or where there is any chance of the backing up of the sewage from the outfall, either because this is—as at Cambridge, for instance—under water, or because the tide rises into it, as in many seaboard towns, it is certain that such percolation does take place to a very great extent. The well-water at Cambridge contains for the most part a good deal of fæcal impurity, which would appear to arise mainly from this percolation from the sewers.

Reductio ad absurdum.

Percolation out of sewer.

Thus we see that constructions which ought to be mainly regarded as drains have come to be *especially looked upon as sewers* (to express this double function we shall call them *drain-sewers*); and while the importance of their being impervious has been strongly pointed out, the necessity for their being capable of acting as drains has been to a great extent overlooked. The extreme importance of this latter point we shall have to consider in another place; suffice it here to say that it is certain that towns must be provided with *pervious drains*, and it is also, from the foregoing considerations, equally certain that they must be provided with *impervious sewers.*

Ultimate change of destination.

Drains and sewers both necessary.

DRAIN-SEWERS.

As these drain-sewers are, however, at present the usual ones employed in most towns, and as in their capacity of sewers they therefore come under our subject matter, we will consider briefly the practical points to which attention should be especially directed in their construction. With regard to their form, some important evidence was given by Mr. Butler Williams, C.E., before the Health of Towns Commission. It is plain that the best form to be adopted is the one which, with the greatest economy of work and materials, combines the greatest power of resistance to external pressure and the greatest facility for the freest flow of sewage contained in it. A very primitive rectangular form, with upright sides and a flag or slate bottom or top, need scarcely be considered, as it obviously does not fulfil these conditions; it combines in fact almost the maximum amount of friction and retarding of the materials passing down it with the minimum amount of strength, and has always been found to fail. The Romans knew very well that an arch was stronger than a flat roof, especially than one made of a single flagstone, and they constructed their great sewers with arched tops. In the form which has upright sides with an arched roof and a flat bottom the friction is as great as in the one above mentioned, and deposit very easily accumulates. When the bottom as well as the roof is arched, as in the Westminster sewers, the friction is very much reduced; while the elliptical sewers not only offer less resistance to the passage of sewage in them, but at the same time greater resistance in every direc-

Form.

Rectangular fails.

Arched roof.

Section

tion to external pressure, while a still further improvement is the substitution of an egg-shaped section for the true elliptical one, the smaller end of the oval pointing downwards. The advantage of this is, "exclusive of its superior strength and economy, that when the water is small in amount the narrowness of the lower part gives a greater hydraulic depth, and therefore produces increased velocity, and, when the body of water is increased, more capacity is obtained." But the question of economy must also be considered, and with regard to this we find, comparing egg-shaped sewers with those of the Westminster form of the same capacity, that while one mile of the former would only require 924,140 bricks, one mile of the latter would require 1,378,080; or "one mile of sewerage of the upright form would require upwards of* half a million of bricks more than one mile of the egg-shaped sewer; and the number of bricks that would complete one mile of the upright formed sewerage would suffice for one mile and a half of the egg-shaped sewer."† The difference would amount to 1116 yards of brickwork, "which, valued at 20s. a cubic yard, would amount to £1116." Besides this, it appears that the "width of the footings used in the upright-sided sewer causes great expense in the excavation," and, taking the average depth of the main line excavations at 20 feet, it is found that 5865 cubic yards per mile is the amount of excess of excavation required in the case of the upright-sided sewer.

Egg-shaped section.

Economy in bricks.

Difference in cost;

in excavation.

This it is reckoned would carry the excess of expenditure to £1660, or altogether "the difference in expense between the construction of upright-sided

* (?) Nearly.

† First Report, Health of Towns Commission, vol. ii. p. 460, etc.

sewers with man-holes, and egg-shaped or arched sewers with flushing apparatus, would be about £1800 per mile, or for 118 miles would be nearly a quarter of a million." The distance of 118 miles is mentioned because it represents the length of main sewers built in London during the ten years preceding the Report. That is to say, that the upright-sided sewers, which offer the greatest resistance to a free flow, in which great accumulation of filth takes place—even to the extent of several feet in depth in some cases—and the sides of which often get pushed in by the pressure of the soil around, as exemplified by several instances cited in the Report above quoted, cost very considerably more than the egg-shaped variety with all its advantages of increased velocity of the current, diminished deposit, and superior strength. Where circular, elliptical, or egg-shaped sewers have been substituted for upright-sided ones, which had previously failed, they have been found to succeed well.

Total difference.

Worst form the most expensive.

It is better that sewers should be too large than too small. We have seen of what an enormous size they may be made, and are made in some cases; but the question is, what is the least size which will answer the purpose, so that the expense of construction may be diminished as much as possible? The general idea is that the mains should be sufficiently large for a man to creep through in order to remove the deposit which may accumulate in them. This is now usually considered unnecessary, as the sewers should be so constructed that occasional flushing will do this.

Should be large.

Common notion.

To take some instances of the sizes actually in use, which will perhaps be the most practical way of looking at it, we find that in the courts and alleys in London, the sizes are from 3 feet by 2 feet 2 inches to

4 feet by 2 feet 4 inches. In streets they are from 4 feet 6 inches by 2 feet 6 inches to the size of the mains, which has been given previously: one of these, despite its enormous dimensions, has recently (1872) been overcharged. In Dover the main valley sewer is $4\frac{1}{2}$ feet by 3 feet. In Salisbury the new sewers are about the same size, and the mains are so constructed that the subsoil water percolates into them freely. In Bristol the main outfall is 5 feet by $4\frac{1}{2}$ feet, and the mains vary from this size to 2 feet by $1\frac{1}{2}$ feet; and it will be found practically that where the drain-sewer system is still carried on, the minimum size for the mains will be about 3 feet 6 inches by 2 feet. This size would allow a man to creep through the sewer easily if necessary.

Sizes in various towns.

It is calculated that a main drain-sewer intended to receive all the sewage of a thickly populated square quarter of a mile, with a water supply of twenty gallons a head, and also the rainfall of the same surface, if equally distributed over every day of the year, would only actually require for these purposes a sectional area of 4 square feet, but that practically, in order to provide for sudden storms, this size would have to be at least doubled. A still larger sewer would be necessary for the same population if spread over a larger area.

Calculated size.

We have already intimated that the mains are generally made of well-cemented brickwork, and it is found that in tolerably good soils they may be (especially the elliptical or oval ones) constructed of single half-brick ($4\frac{1}{2}$ inches) thickness. Where they are required to be unusually strong, they may be one brick thick. In many towns stoneware pipes are substituted for the brick sewers, in the smaller streets at any rate. At Rugby, 6-inch pipes are used for small streets con-

Brick-work.

Pipes for small streets.

taining fourteen or fifteen houses. This is, however, too small a size for sewers; they should be, as in other towns, 9 or 12 inches in diameter; such pipes (18 inches in diameter) may be even used for the larger streets, but this economy is especially undesirable, because these pipes, being glazed and impervious, do not at all act as drains; and, in fact, brick mains built so that the subsoil water can enter them (a sufficient fall and occasional flushing being relied upon for the prevention of percolation of sewage into the surrounding subsoil), should be constructed in preference to these pipes in all the large streets in towns where a single system is allowed to remain in use.

Pervious mains preferable.

Curved at junctions.

The junctions of the various branches should not only be made at as acute an angle as possible, but the smaller branches should be somewhat curved, so that there is no angle to offer an obstacle to the free entrance of the sewage into the main. It is desirable also that the points of junction should not be low down in the main, so that the sewage from the pipes or smaller sewers may not have to encounter any considerable pressure.

Depth.

Below cellars.

Drain-sewers must be placed deep enough to drain the subsoil; and, above all, must be placed below all cellars. There are too many instances of cellars having been—or even being continually—flooded, because they were below the level of the sewers. The sewers must drain the cellars; not the cellars the sewers! This is the case especially when the sewage is backed up from the outfall, or when the gradient is small. Thus, at Bedford the street sewers are described in Mr. Austin's Report as "chiefly built with bricks laid flat in the lower part, and without any mortar. In some cases the sewers are at such little depth that cellars of houses are accustomed to receive the foul liquid which filters through these defective constructions." * The new sewers in most of the towns have been placed at such depths as "from 16 feet (in the mid town) to 4 or 5 feet in many other parts of the town" (Stratford-on-Avon). At Rugby they are "at an average of 11 feet from the surface, varying from 7 to 25 feet." At Worthing they begin superficially, and are 20 feet deep at the outfall. The London sewers vary much in depth. Examples.

The incline to be given to sewers must necessarily, as we have before stated, depend to a very great extent on the natural inclination of the land itself, but where choice can be had it would appear that house-sewers should have a fall, if possible, of 1 in 20 or 30; the usual fall of 1 in 48 is perhaps sufficient for the pipe sewers, while for street sewers and mains the inclination should vary from that just mentioned to 1 in 200, or 1 in 250. It is certain, however, that in many cases such an inclination cannot possibly be got, and then the engineer must rely upon the good shape of the sewers and sufficient flushing to keep deposit from accumulating. Incline. Not always possible.

As these constructions are really drains used as sewers, their natural outlet is into the nearest water-course or into the sea. In the latter case, and in the mouths of tidal rivers, the tide often passes up them, and backs the sewage into the street sewers, whence it may overflow into cellars, or even come up through the gully-holes into the streets. This was found to be the case at Dover with the old sewers. When the outlet is into a river, below the level of the water, the sewage is backed up by the pressure of the water in Outlet. Backing up in mains.

* Third Report M. O. P. C., 1860, p. 41.

the river, and unless the fall of the mains be considerable, and the velocity of the sewage sufficient to carry it out into the river, it will be, as at Cambridge, backed up almost continually, and the main converted into a long cesspool. At Salisbury the outfall is into the Avon by a brick main, the open mouth of which is a foot above the lowest summer level of the water and a foot below the ordinary level. At Worthing the outfall—which is 20 feet below the surface—opens into a tank, out of which the sewage is pumped continually; but when the pump is not at work, sewage accumulates in the well, and even when the sewage has been delivered in amount beyond the capacity of the pumping power, "it has filled the well and backed up the sewers," and, in prolonged wet weather, "has regurgitated into basements of certain houses." At Bedford the chief outfall of the sewage was formerly into the river above the town, so that the water was polluted with it before it reached the town.

Outfall into tank.

Where the outfall is into a tidal river, or into the sea, a very usual plan is to provide a sluice, which is shut during each high tide; by this means the tide is prevented from rising into the sewer, but the sewage is backed up in the mains, which become cesspools for the time being: a better method is to have a large receiving tank into which the sewage is allowed to flow during high tide.

Sluice to shut out tide.

As a summary, then, the outfall should be so placed —unless it is absolutely impossible—that there is no chance of any resistance being offered to the escape of the sewage; and it is obviously wrong to allow it to enter into a river close above a town, or even close below it in the case of a tidal river. Whether it is right or not to send it into a river at all is

Position of outfall.

another question, and will be considered in another place.

From the Ninth Report of the Medical Officer of the Privy Council we find that in the towns which have been supplied with brick sewers, properly cemented, the subsoil water has in all cases been considerably lowered, unless from some local peculiarity which keeps the subsoil permanently wet. This is the case at Bristol, where, although there is no doubt that in many parts the underground water level has been lowered by the passing of the sewer through the porous soil, yet in other parts the water has kept up some sixteen feet above its natural ebb level by the influence of the floating dock; and it appears "that the wells (generally speaking) are unaffected in their supply of water by the sewerage" (p. 63). At Cheltenham, where Dr. Wright insisted that in the construction of the sewers "the removal of subsoil water was to be kept in view," the drying of the subsoil has been very considerable, although the Chelt is backed up within the town by mill-dams (p. 89). At Macclesfield, it is stated that "there is now no subsoil water above the level of the sewers anywhere, and cellars that used to be flooded are now dried by the sewers" (p. 117). The most remarkable instance of this drying of the subsoil is perhaps to be found in Salisbury, where the soil is a very porous gravel, containing much water. It is stated that in past times "there have been several instances of the Cathedral being flooded by the water of the subsoil; the foundations of the houses are almost without exception damp." The wells are "dug about eight or ten feet deep, the water rising to within two or three feet of the surface." Since the sewerage works have been finished it is said that "in the main sewer

Subsoil water lowered,

even when artificially backed up.

Best instance.

a rapid run of water from the subsoil always exists . . . cellars of considerable depth can be made, even at the lower parts of the town, and these do not become flooded at any time. On an average the subsoil water has been lowered four or five feet over the city. The Cathedral has never been flooded since the drainage works." (*Loc. cit.* p. 150.)

Cellars no longer flooded.

From the Rivers Pollution Commissioners' First Report (1868), vol. ii. p. 83, we find that at Waterloo-with-Seaforth, where the works have consisted of brick sewers, earthenware pipes, and cast-iron pipes, "the extent of well water is greatly depressed, so much so that many or most of the wells are useless;" but as a general rule the towns in these basins (Mersey and Ribble) do not seem to have had their water level much altered by the sewers. The level would seem to have been most affected where the subsoil is porous, as at Salisbury and parts of Cheltenham. Where it is a stiff clay it would appear that generally the drying has not been so effectual. This drying of the subsoil appears to have been pointed out to the Health of Towns Commissioners in 1844, by Mr. John Liddell, who says, when questioned upon this point: "I believe the sewer has been useful, and has considerably diminished the surface water, in some places so much so as to reduce the amount of fever."

Wells dried.

Nature of soil.

Cambridge was one of the towns reported on by the British Association Sewage Committee of 1869-70; it was found that (see *B. A. Report*, 1870, p. 60)—

Backing up of sewage.

The outlets of the public and private sewers are all under the level of the surface of the water in the Cam, consequently the sewage is backed up in the sewers for a considerable distance, and the subsoil is constantly saturated with both water and sewage in the lowest parts of the town.

Inquiries were made into the state of some of the wells belonging to private houses, and it was found that they were all contaminated by sewage, owing to their proximity to the sewers in the streets and to the drains on the premises—so much so, that the water cannot be used for drinking, but only for washing. Contamination of wells.

This is the natural result of the *drain-sewer* system, and led the Sub-Committee before named (see p. 61) "to give expression to the conviction forced upon it in the course of its inquiries, that all sewers properly so called (that is to say, drains into which refuse from human habitations is admitted) ought to be constructed of materials which are altogether impervious, and that a separate system of pervious drains, similar to agricultural drains, should be constructed where necessary to dry the subsoil. *The Sub-Committee is of opinion that the further construction of pervious sewers should be prohibited by Parliamentary enactment.*" (The italics are ours.) Sewers must be impervious.

The drain-sewers, then, as usually constructed, do act efficiently as subsoil drains.

THE SEPARATE SYSTEM.

In some towns impervious glazed stoneware pipes have not merely been used for the house sewers and in the smaller streets, but have been employed throughout. Thus, at Penzance the storm water and ordinary surface water is allowed to go along channels in the streets to the sea, while the whole of the sewage of the town passes through impervious pipe sewers ranging in size from fifteen inches in the main sewer to four inches for the house pipes. They lie at an average depth of 9 feet, and their incline varies from 1 in 120 to 1 in 15. They have "two brick outfalls into the sea, one below low-water mark, while the other is uncovered for three to four hours of the tide; Impervious pipe sewers. Brick outfalls.

into these outfalls the storm water is also received." Houses are drained into the sewers on the block plan, the inlets to all drains being trapped. Deposit rarely accumulates in these sewers, and for the purpose for which they are intended they answer well; but it must be remembered that there are no subsoil drains.

Examples.

At Carlisle the same system was applied by Mr. Rawlinson, the outfall of the sewer being 3 feet 9 inches by 2 feet 6 inches, "with the small but sufficient fall of 1 in 1000," and the others ranging from this size down to 9-inch street pipes.

Discharge into the sea.

At Dover the pipe system of sewers has been added to the old system of drain-sewers, which are still left to carry off the storm water. The pipes vary from 6-inch house pipes to 18-inch sewers, which open into a brick main $4\frac{1}{2}$ feet by 3 feet. The pipe system discharges into the sea at low water by gravitation; pumping has had to be resorted to during the spring tides from the flooding of the cellars.

Separation of storm water from sewage.

At Chelmsford the greater part of the storm water is allowed to pass off "by surface channels and by superficial culverts, to the river," while the sewage and house drainage generally is conveyed in pipes to a pumping station at the lowest part of the town. The outlet of the culvert into the tank is "of brick, 15 inches in diameter, and 6 feet below the surface." All the other sewers, large and small, are impervious pipes. When pumping is not going on from the tank, the outfall can be closed by a sluice, and then the sewage accumulates in the mains. (*Ninth Report M. O. P. C.*, pp. 147, 107, 132, 156.)

Ely and Rugby are both supplied in the same way, the storm water still going along the old sewers. In Rugby, pipes only 6 inches in diameter are used for the smaller streets containing fourteen or fifteen houses, and the main outfall is only 2 feet in diameter. At Stratford-on-Avon the chief difference is that the pipes are larger, the smallest street sewer being a 9-inch pipe, and that they receive the storm water, as also the drainage of houses. Gloucester, Southampton, Leamington, and other towns afford instances of the application of this system. The pipes used for these sewers have the advantage of being very strong: they can be much more quickly laid than brick sewers built, and there is, with a proper incline, almost no chance of accumulation taking place in them. They require a much smaller amount of excavation than brick sewers, and they can be made with very various curves to suit different positions. From the Rivers Pollution Commissioners First Report (1868), vol. ii., we find that a considerable number of towns in the Mersey and Ribble basins are supplied partly with pipe sewers, though the mains are generally egg-shaped brick sewers. These should be constructed of well-burnt impervious bricks or preferably of glazed fire-bricks. On the whole, there is no doubt that glazed earthenware pipes act perfectly well as sewers, and efficiently remove all the refuse matters with very little chance of accumulation.

Size of pipes.

Advantages.

Act well as sewers.

Up to 18 inches internal diameter, sewers should be made circular in section. Stoneware or concrete pipes will be found better and cheaper than brick sewers of this size. Mr. Baldwin Latham, writing on concrete or cement sewers, says (*Sanitary Engineering*, pp. 206-208):—

Cement or concrete pipes.

Cement pipes of large size, with socket joints, are now extensively used in Germany, and they withstand, not only the effects of a severe climate, but the chemical action of the sewage, and are produced at con-

Their endurance.

siderably less cost than either a brick sewer or a pipe sewer of equal calibre. Moreover they show an extraordinary amount of endurance, and remain perfect after severe frost, when brickwork often fails. It is a material that can be worked and moulded into any form, and maintains its form when made. . . . These pipes improve materially by age . . . cement pipes are perfectly water-tight, and are by no means so brittle as ordinary earthenware pipes. A blow that would shiver in pieces an earthenware pipe would simply drive a hole into a silicated concrete pipe. A concrete pipe is capable of withstanding the jars arising from heavy traffic over the streets, even better than an earthenware pipe, which is a quality of no small advantage, as the author has found that in some districts, earthenware pipes have been found to split in a singular fashion, the cause of failure being due to the constant tremor of heavy traffic in the streets.

Cement or silicated concrete pipes are, like stoneware pipes, impermeable to water, and should consequently only be used in place of stoneware pipes, other means being adopted to drain the subsoil.

Pipe sewers in running sand.

When pipe sewers have to be laid in loose sandy soils, considerable difficulties arise, which usually effectually prevent their being impervious; indeed subsoil water gets into them, and issues from their mouths as soon as they are laid: this is "in consequence of the cement, even when covered with a clay lute, getting washed into the sewers before it has time to set." Cast-iron pipes have been proposed in such circumstances, but Messrs. Reade and Goodison, of Liverpool, have, in the British Association Report for 1870 (*Transactions of the Sections*, p. 222), described a plan by which the difficulties just alluded to are obviated.

Subsoil-drain and pipe-rest.

They have introduced a subsoil-drain and pipe-rest (manufactured by Messrs. Brooke and Sons, of Huddersfield) of the form of the letter ⌓, which is first laid in the bottom of the trench and jointed with clay, like an ordinary pipe sewer. This has the effect of lowering the subsoil water, so that the sewer proper can be laid upon the movable saddles or rests) fitting the curvature of the drains and the sewers) undisturbed by water or running sand. By these means the cement joints can be made perfect all round, and have time to set before the trench is filled up. True gradients are insured, as the pipes can be leisurely laid ; and as the pipes are jointed over the *middle* of the subdrain, a continuous foundation is secured. A more perfect drainage of the subsoil is also found to result, the general level of the water being reduced to nearly the level of the invert of the sewer.

This plan is well worthy of consideration, as there are many places where difficulties have arisen in the laying of pipe sewers so that they shall be, and remain, impervious.

Invert blocks.

In the case of brick sewers, hollow stoneware invert blocks are now very generally used. Besides affording a passage for subsoil-water during the construction of the sewer, their smooth hard upper surfaces form an excellent floor for the sewer.

Pipe sewers do not lower the subsoil water.

Where the pipe system has been employed, especially if to the entire exclusion of even brick mains, no drying of the subsoil has taken place. At Penzance, "the effect of the construction of sewers upon the subsoil of the town has been inconsiderable, if any. . . . No wells were affected at all by the drainage works." At Rugby there has been a slight lowering of the subsoil water, but to no great extent. At Penrith, Alnwick, Morpeth, and other places, there has been no change in the subsoil water. At Worthing, however, where there is, be it noted, an egg-shaped brick main, and where the surface water is allowed to run into the pipe sewers, while the storm water is partly carried off by the old brick ones, the removal of the subsoil water has been considerable ; but this has been to a great extent due to water finding its way alongside of the pipes, the town standing on semi-porous strata. We may note that at Morpeth, although there is no draining of the subsoil water, "the surface is rendered incomparably dryer," and the cellars that used to get filled with water in all heavy rains have

Water finds its way alongside of pipes occasionally.

never been flooded since the sanitary works. At Ashby-de-la-Zouch, it would appear that the subsoil water has been lowered, probably from the water finding its way alongside the pipes, and from the very fact that excavations have been made through the thick tenacious clay upon which the lower parts of the town rest. (*Ninth Report M. O. P. C.*)

Mr. Menzies' plan.

Some of these towns, then, it will be seen, are, as a matter of fact, provided with sewers much upon the plan which Mr. Menzies has the credit of having first brought prominently forward; that is to say, with impervious pipes for the sewage properly so called, and brick drains for the surface and storm water, the former being laid deeply and the latter being superficial. We have, however, seen that by this system no provision is practically made for the removal of the subsoil water; only the sewage and the surface water is attended to. That this is not sufficient, but that it is necessary for "the subsoil water to be removed, and kept at an adequate depth below the surface by under-drains specially laid for the purpose," as Mr. Bailey Denton says, we shall show when we describe the effect of sewerage works upon the health of towns.

Necessity for removal of subsoil water.

Street water into drains.

Where this "separate" system is adopted, Mr. Menzies says that the street gullies should open into the drains, and not into the sewers; he considers that the street scavenging ought to be sufficiently well done to prevent any great amount of organic refuse matters being washed into them in this way.*

In a lecture on "The working of the Separate System of Sewerage," delivered at the Parkes Museum on 21st January 1886, by Mr. R. F. Grantham, A.M.

* Paper read before the Institution of Surveyors, 19th April 1869.

Inst. C.E., a very interesting comparison is made of the quantities of sewage to be dealt with in two towns similarly circumstanced in every respect, except that one is sewered on the combined, and the other on the separate system. From 1871 to 1876 observations were conducted by a Committee of the British Association on the quantity of sewage delivered from the town of Romford on to the sewage farm. The sewers of the town received both rainfall and the sewage from a population of 5297, and a considerable quantity of subsoil water infiltrated into them. The actual quantity of sewage pumped and utilised on the farm amounted in the year 1872-73 to nearly 107½ million gallons; in 1874-75 to 108 million gallons; in 1875-76 to 122½ million gallons. The largest quantity in any one week during those periods amounted to 3,662,000 gallons, and the smallest representing the dry weather flow was 1,321,000 gallons, equal to about one-third of the highest. The water supply to Romford at that time was about 10 gallons per head per diem.

Comparison of quantities of sewage in the combined and separate systems.

The sewage of Romford.

About three years ago the town of Slough, which then possessed deep laid brick sewers, was provided with a system of pipe sewers laid slightly above the level of the old sewers, but still sufficiently deep to drain all the houses in the town of their water-closet sewage and house-waste waters, leaving the subsoil water and the storm water to pass through the old sewers. About 8½ miles of pipe sewers, varying from 9 inches to 15 inches in diameter, were laid; 1200 yards of the outfall sewer being cast-iron, 15 inches in diameter, and jointed with lead and gasket, to prevent the entry of subsoil water. The outfall sewer empties into two storage tanks, from which the sewage is

The sewage of Slough.

pumped up a height of 25 feet to a sewage farm laid out on the broad irrigation system, with ridges and furrows, 40 feet from ridge to ridge. The population of Slough at that time was 5200, and the water supply about 10 gallons per head daily. The quantity of sewage pumped on to the farm was found to be for the year 1882 not quite 27 million gallons, for 1883 rather more than 33 million gallons, and for 1884 not quite 30 million gallons. These figures afford a very striking contrast to those representing the volumes pumped at Romford.

Surface-water outfall not productive of nuisance.

The outfall of the surface-water drain at Slough discharges into a ditch by the side of the public road, within the statutory 3 miles distance from the river Thames, over which the Thames conservancy has jurisdiction, but no complaint has ever been made. As a general rule it would probably be more satisfactory to include in the sewage requiring purification the surface waters from the backyards of houses, as these are often of a somewhat polluting nature, and may give rise to nuisance in the storm-water drains.

Cost of the Slough sewerage works.

The cost of the entire system of new sewers at Slough, including engines, pumping station, tanks, rising main, and preparation of land was about £17,000. The cost of the original sewers now used as surface-water drains was between £5000 and £6000. Mr. Grantham remarks :—

Results encouraging.

It will be clear, without much calculation, that to have enlarged the main sewers to include rainfall, to have added to the tanks, increased the power of the engines and capacity of the pumps and rising main, and to have taken more land, would have involved cost considerably exceeding £6000, without reckoning the increased cost of working the pumping engines and managing the land. Slough, it is believed, is the first town in which the separate system has been carried out in its entirety throughout, and in which the results have been measured and recorded. They are so far encouraging that I believe all towns of the same size would find it economical to adopt the system; and further, I consider that there is no difficulty in applying it to much larger towns, from which I expect equally good results would be obtained. If thoroughly adopted, sewage utilisation would be freed from one of its greatest impediments.

One of the most complete examples of the separate system of drains and sewers, as yet introduced, is furnished by the city of Memphis in the United States. The plans of these works were designed and carried into execution under the direction of Colonel Waring. We abstract the following account from a report on the system at Memphis made for the city of Baltimore by Mr. C. H. Latrobe, C.E., which is given in the Second Annual Report of the State Board of Health, New York, 1882:— The separate system at Memphis.

Memphis is situated on the Mississippi river, and contains a population of 35,000. The work was commenced in January 1880. The system is based upon a flow of about 40 gallons of sewage per head daily. The main outlet sewer is 20 inches in diameter and built of brick; all the other sewers are of burnt and glazed clay pipe, ranging from 15 inches to 6 inches in diameter, the latter being the size adopted for nearly all branch sewers. Common tile drains 1 to 3 inches in diameter are laid in the same trench, for the drainage of the subsoil, and at the proper points are carried off to empty into the nearest watercourse, into which also storm waters are permitted to flow on the surface of the soil. At the dead end of every branch sewer is placed an automatic flushing tank with a capacity of 112 gallons. Each tank is filled from the city water supply through a pipe and spigot, so arranged as to flow continuously, with a sufficient stream to fill the tank in twenty-four hours or oftener if desired. As soon as the tank is filled to the proper height a siphon comes into play, and the tank is rapidly emptied into the head of the sewer. There are over 20 miles of sewers and 125 flush-tanks at work in Memphis, the total cost of which, including expenditures of all kinds, has been about $137,000 or $685 per mile (about £137). (The estimates for the combined system for the town were from $800,000 to $2,225,000). The flush-tanks consist of a brick chamber built on a concrete bottom, set below the level of the street, and covered with a perforated lid; in the centre of the tank is an annular siphon, which discharges into a box underneath it, and thence into the sewer. These tanks are found to fill and discharge the 112 gallons with the most perfect regularity in from 40 to 50 seconds. The gradients of the branch sewers are from 3 to 6 inches in 100 feet, and the rush of water from the tanks is distinctly felt at a Drainage of the subsoil. Siphon-action flush-tanks.

distance varying from 400 to 900 feet, keeping the pipes perfectly clean. No tendency to freeze has been noticed in the tanks, although the temperature of the air has been as low as 4° Fahr. Whenever practicable the branch sewers of Memphis are laid in alleys at the rear of the houses, which prevents the necessity of carrying the house soil-pipe to the front of the house. The main house pipe is required by law to be 4 inches in diameter, and to connect with the sewer without a trap ; its upper end is carried above the roof of the house, full size, and left open ; each water-closet, kitchen sink, bath tub, and waste sink connects with this 4-inch pipe by a trap-connection of its own. The varying height of the 4-inch house mains, together with the constant flow of sewage, stimulated by the intermittent discharge of the flush tanks, keeps the whole system well ventilated and in good order. The main and outlet sewers have an inclination of from 1 in 400 to 1 in 600 feet, and the sewage is finally discharged into the Wolf river, near its confluence with the Mississippi. On an inspection of the main and outlet sewers at 11 A.M. the sewers were seen to be running three quarters full with a swift current. Nothing solid of any sort was to be detected in the flow even by dredging, an occasional piece of paper constituting the only undissolved matter ; everything was in solution, and the sewage was about the colour and consistence of the Mississippi river water. Although in several places the entire crown of the sewer had been removed it was difficult to detect any odour until within 2 or 3 feet of the flow. To assist ventilation and afford means for inspection, it was originally intended to place a fresh-air inlet at every junction of a lateral sewer with the main, this being covered by a grating so arranged as to let in air and keep out dirt. Only nine of these fresh-air inlets were made, from the belief that they were unnecessary. The only deposit which has been ever noticed in the mains is a fine silt of moderate tenacity, supposed to be a mixture of the mud held in solution by the river water (used for filling the flush tanks), combined with the pulp of dissolved paper. This silt is readily washed out by passing the "ball" through the mains from manhole to manhole. A hollow ball of galvanised iron having an inlet and stopper, and about 3 inches less in diameter than the sewer, is charged with water sufficiently to keep it in contact with the roof, along which it rolls ; it is then dropped into the sewer at a manhole, the current instantly gorges, and rushes under the ball with great velocity, scouring the bottom of the sewer, the ball in the meantime rolling along the roof of the sewer. The ball can be stopped if desired at the next manhole and taken out. Balls of different sizes are used as desirable. The above mentioned deposit of silt in the mains has never been more than 1 or 1½ inch in depth. The only obstructions which have occurred (thirteen in number) in the branch pipes during the 12 months, in which the system has been in use, have invariably been occasioned by sticks about 6 inches long getting across the pipes. The obstruction is immediately located by the rising of the sewage in the yard waste

House-drains connected with sewers without traps.

Fresh-air inlets.

Silt washed out by passing the "ball."

sink of the house just above it. The sewer is then uncovered at the proper place, cut open on top, and the obstruction pulled out with a hook of twisted telegraph wire. This would seem to indicate that any slender article, not over 6 inches long, will pass through a 4-inch trap, and this is further proved by the fact that a number of 2-feet carpenters' rules, which fold to 6 inches, have been taken out of the sewers. No obstruction has ever taken place in the 8, 10, 12, 15 or 20 inch mains. Not a single case has occurred of the breaking of a pipe. As to the house arrangements the regulations are stringent; no plumbing is allowed on any plan but that adopted by the authorities, and carried out under a rigid inspection by the engineer, and no house is permitted to connect with the sewer until inspected and passed.

Removal of obstructions.

Every outlet for waste is connected with the 4-inch house pipe and trapped; a slop waste is insisted on for each house, so that nothing is thrown into the gutter or on to the soil. No pan closets or Bramah closets are allowed where there is an air space between the trap and the pan; the use of some form of hopper closet is preferred. All connections with sewers are made by Y's and not by T's. The city lays a branch every 24 feet to the curb (pavement), to this the householder joins his iron 4-inch house pipe. This avoids tearing up the street to make house connections. By gaugings taken it was found that the hourly flow of sewage is markedly uniform. Taking the twenty-four hours the minimum flow is 43·7 per cent of the maximum; taking the twenty hours of greatest flow, the minimum is only 84 per cent of the maximum. This oscillation within such small limits must be somewhat influenced by the action of the flush-tanks, which probably discharge in small groups. A force of about four men watch and keep in order the entire system, including the flushing tanks, house visitations etc. The system of tile drains has, as far as known, thoroughly drained the very tenacious subsoil of the city. As to the storm water at Memphis, it can be safely left to take care of itself. (Memphis is situated on ground sloping to the river.) An error in the system at Memphis is the omission of manholes in the mains, as well as means of opening the small pipes, without breaking them, to remove obstructions which will sometimes occur. These omissions are now being remedied, manholes being constructed at every 500 feet on the mains, and when a section of small pipe is broken into, it is replaced by a T piece with a lid on the top of the upright stem, which can be readily removed and the cleaning tool introduced. Another error that has been made is not using the fresh air inlets, as originally intended, at the junction of branch sewers with the mains. They are useful both for ventilation and observation.

Hopper closets preferred.

Flow of sewage.

Manholes being constructed.

Pullman near Chicago is also sewered on the separate system, on a plan very similar to that designed for Memphis by Colonel Waring. Owing to the

Adoption of the separate system in America.

success which has attended the system at Memphis and Pullman, numerous other towns in the States propose to adopt similar sewerage works. In 1883 the small quarter of Paris known as Marais was provided with pipe sewers, the existing brick sewers in this district being now only used for the reception of rain and surface waters. The adoption of this system in Paris—where it is best known as the *Waring system*—has been attended with very great success. In this country Reading, Oxford, Slough, Halstead, and other towns have adopted the separate system—more or less modified in details according to circumstances. Most of the witnesses before the Royal Commission on Metropolitan Sewage Discharge were in favour of the principle of separation; which also has one of its ablest and warmest supporters in Mr. Edwin Chadwick. The application of the system to the metropolis is, however, surrounded with such difficulties and obstacles that the present century is hardly likely to see its adoption in any but a very partial manner.

In Paris.

In England.

Application to London.

FLUSHING OF SEWERS.

That in brick sewers, especially badly constructed ones, and in such as have not a sufficient incline, considerable accumulation of semi-solid filth may take place, in spite of the fact that rain and storm water pass along them, has been already pointed out. This happened in the Cloaca Maxima, which got choked up, and had to be cleaned out at a cost to the Censors of 1000 talents.* The old method of removing this deposit was through manholes by spade and bucket. That this is a very expensive method will be seen

Accumulation of deposit.

* Dionysius (Halicarnassus), Antiq. Rom. iii. 200.

from the statement that "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" (Bazalgette on the *Main Drainage of London*), and from another in the Health of Towns Commissioners' First Report, that the yearly expense of cleansing the sewers in Westminster was £2000, the number of loads of deposit removed annually by carting being 6000. In the same Report (vol. ii. p. 159 etc.) the advantages of flushing by water, instead of removal by the above method, are put forth. It was shown that in some cases where the deposit was 3 or even 4 feet thick, and had stopped up the sewer, not only the street had to be broken up, but the arch of the sewer broken into also, and the soil raised to the surface and carted away, causing a very great nuisance to the neighbourhood. The cost for removing it, if the sewers had manholes, was 6s. 10d. a cubic yard; if they had not, 11s. a cubic yard, on account of breaking open the arch and making it good again. The results of some experiments that were made to ascertain the flushing power of water are given, and it is shown "that a velocity of 6 inches in a second would be sufficient for scouring away all the usual sediment, and that a velocity of one foot in a second would sweep away fine gravel." In some other experiments with a flushing-gate, 4 feet high—the quantity of water headed up for one flush being 26,605 cubic feet—it was found that, by a single flush, brickbats were carried along for a distance of from 261 to 529 feet. By a second flush the foremost brickbat had reached 1170 feet; "after the third flush the whole were found to have passed a distance of 1300 feet." The whole bricks were carried from

Expense of removal.

Evils of old method.

Experiments with a head of water.

Bricks flushed away.

248 feet to 760 feet by one flush, and by the second flush the foremost brick was carried 160 feet farther. These experiments demonstrate very clearly the effectual flushing power of a head of water backed up by a flood-gate. It need scarcely be pointed out that much time and money is saved by flushing. "It was found on calculation that the cost of putting down one of these flushing apparatuses (a mere board dam) was less than cleansing the sewer in the old way, while the apparatus remained for future use at no more expense than the men's labour." In an instance where 6688 yards of foul deposit had been removed by flushing, it was calculated that—as the whole cost of removing it by hand labour would have been £2387, while the cost of putting up the inside apparatus and flushing-gate was £1293, and the cost of men's time £644 : 12 : 7—"there was then a saving of £455 to the Commission," besides the fact that on account of the side entrances the pavement would no longer require to be taken up as before, and the apparatus would remain to be used when required. In the Holborn and Finsbury district it is stated that at that time (1844) about two-sevenths of the sewers were supplied with flushing apparatus, and that while "the annual cost of cleansing those by the old mode would be £326 : 17s., the cost for men to work the gates now placed, that is, keeping the sewers clear from deposit, is £106 per annum, leaving a saving of £220 per annum on these two-sevenths." (*First Report H. of T. C.*, vol. ii. p. 164.)

Saving by flushing.

Several examples.

Paris plan, movable flushing-gates.

Instead of having flushing-gates at certain points in the course of the sewers, which can be let down so as to dam up the sewage, and cause a sufficient head to sweep the sewer clean when the gate is raised, the

Paris sewers are provided with a kind of movable flushing-gate, carried by a truck running on rails, which are placed one on each side of the actual channel; the truck being driven forward by the pressure of the sewage against the flushing-board, while the latter clears the sewer as it passes, being much assisted by the rush of sewage past its edges, which well stirs up and carries along the mud.

At Bristol the main sewer "is not ventilated or flushed, and is stated to require neither one nor the other, as there is no deposit in it, and never any accumulation of foul gases:" and here we may anticipate a little, and say that foul gases are not formed to any great extent in sewers where no accumulation of filth takes place; it is by the fermentation going on in a semi-solid deposit of filth at the bottom of a sewer that foul gases are generated, and where flushing is adequately performed so that no deposit accumulates, the sewers will be found to be very free from foul air. At Leicester "the sewers are flushed at their two highest points from a thousand-gallon tank filled by a hydrant with the water company's water. . . . Without great care in flushing, the sewers are apt to get a deposit of silt." At Cardiff the flushing is performed "by the surplus water from a channel which feeds the docks. . . . For parts where this is not available, a special flushing reservoir is constructed." At Salisbury, with the pipe system, there are flushing wells constructed at the corners of the streets, from which the pipes are flushed through hydrants when needed. "The sewers, after ten years' experience, are found to act well, and to have no deposit but what is easily got rid of by flushing regularly once a fortnight, with extra attention to some sewers that are nearly

No deposit; no foul gases.

Various methods of flushing.

Deposit effectually prevented,

on a level." At Penzance and Chelmsford the pipe sewers are rarely flushed, but do not choke or silt up. At Rugby, where the sewers frequently got choked up when the gradient was small, the establishment of flushing chambers to clean such parts has obviated all inconvenience on this head. At Alnwick the pipe sewers are *flushed once a day*, the contents being removed so rapidly that at night the outfall chiefly consists of water from the waste of the houses and the interception of springs by the sewers (*Ninth Report M. O. P. C.*) At other places, as at Garston, Accrington, etc., watercourses can be turned through them where the fall is bad, or arrangements are made for flushing them by hydrants from the mains at certain intervals.

even where insufficient incline.

Streams sometimes used.

With the "separate" system of sewerage, the pipe sewers might be made to communicate at certain intervals with the rain-water drains, and might be flushed when they required it, by letting water from these latter run into them.

By communication with drains.

It is certain, however, that with well laid pipe sewers the flushing caused by the amount of water-closet and house slops will generally suffice to keep them free from deposit.

Dr. Trench, in his evidence before the Rivers Pollution Commissioners (1868), after pointing out that "in a well-drained midden, not only do the whole fluids reach the sewers, but it may be also asserted that in rainy weather much of the solid matter will be also carried away in a moist and disintegrated state," adds:—

Importance of water-closet to sewer.

Now the difference between the water-closet and the privy is, that in the former the flow of water is so regulated as at once to take the sewage along the private or house drain into the main sewer, from which, as has been proved by experiment, it will reach the river in 60 minutes from the most distant parts of the borough (Liverpool); while in the latter, or privy-drain, no such impetus is given by water as a moving power, and the sewage dribbles into, stagnates, and decomposes in the drain before it reaches the main sewer. Indeed, so perfect is the daily flushing power of what are termed the trough water-closets in courts, that never now we perceive those emanations from the grids at the entrance of courts which were common during the period of court privies. (*First Report R. P. C.*, vol. ii. p. 303.)

Conclusions.

With pipe sewers where the incline is good, as at Brynmawr, where it is stated to be 1 in 30, no flushing whatever is required. The towns examined by the Rivers Pollution Commissioners show the truth of this statement very forcibly. Wherever there is a good gradient, as at Hurst, Mossley, Toxteth Park, and in most of the main sewers of Manchester, Bolton, and other places, no flushing is required. At other towns, some kind of waste water, as that of a pond or brook, or even of a swimming-bath (Monks Coppenhall), is employed for this purpose. In some the sewers are only flushed by storm water, while in a great many instances arrangements are made for flushing them from the mains, either by means of flushing reservoirs, or merely by pipes or hose through the gulleys. Where sewers do require flushing, it is plain that it will not do to trust merely to the rain-water for this purpose. It is during the summer months when there is least rain, and therefore a smaller body of water passing down the drain-sewers of such towns as London, that the great accumulation of filth takes place in them, and it is precisely during the same summer months that these dangerous accumulations are most dangerous, on account of the decompositions which are set up in them and greatly facilitated by the heat of the weather; and so in the case of sewers which do not sufficiently flush them-

No flushing required where the gradient is good.

Not trust to rain water.

Flushing necessary when gradient is small.

selves because they cannot have a sufficient gradient, it is absolutely necessary that they should be regularly flushed by artificial means, or manholes should be provided, giving easy access to the sewers at different points, so that accumulations of deposit may be removed from them by hand labour.

Manholes into sewers.

Manholes may be perpendicular shafts entering the sewer over or immediately at the side of its crown; or in the case of streets where the traffic is great, as in London, a short perpendicular shaft may be sunk under the footway, and a passage be cut from the bottom of this shaft with steps leading down to the side of the sewer. These side entrances are not so cleanly as those opening into the crown of the sewer, as in times of flood the sewage may leave detritus on the steps of the passage, which subsequently decomposes and gives rise to offensive effluvia.

As deposits in sewers are brought about by the irregularity of the flushing that they get from the rainfall, it has been proposed to supplement this when necessary by sending a rush of water down them occasionally, and this is the method now usually adopted.

Collection of rain-water.

To provide a supply of water for this purpose, a plan of collecting the rain water from the roofs of houses is described by Mr. W. D. Guthrie (*First Report H. of T. C.*, vol. ii. p. 243), which could certainly be very well adopted in most towns. The water is merely received into cisterns which communicate with the drain-pipes, the aperture of communication being closed by a movable plug, so that the contents of the cistern can when necessary be suddenly emptied down the sewer so as to clean it. It was, however, recognised by several witnesses who gave evidence before this Commission, that sewers when properly constructed ought to require no such artificial relief. They ought to flush themselves continually, and this plan has been adopted in a considerable number of towns, especially in such as have pipe sewers placed at a sufficiently good inclination.

Sewers should flush themselves.

Automatically discharging flush-tanks may be placed at the heads of house drains. They should not be placed as they sometimes are, at the top of the house, so as to discharge into the upper end of the soil-pipe, for the sudden passage of such a large volume of water down the soil-pipe will, unless special precautions be taken, unseal the traps of all the water-closets which discharge into the soil-pipe. Siphon flush-tanks are preferable to those which are constructed with moving parts. The waste water from a sink entering them will be sufficient to start their action, or they may be regulated by the dribble from a tap to discharge once, twice, or several times in the twenty-four hours.

Siphon action flush-tanks at the heads of house drains

VENTILATION OF SEWERS.

Wherever there is the least chance of any stagnation of sewage taking place, the same changes occur in it as in the case of cesspools, and offensive gases are given forth in large quantity from the decomposing mass. That these gases are of the same nature as those found in cesspools was insisted on by Parent Duchatelet; and with regard to ventilators he says: "Of everything which belongs to the construction of sewers . . . there is nothing so important as eye-holes (*regards*)," and he suggests that the sewers should be ventilated by means of a large pipe, such as

Importance of ventilation.

has been described in the case of the *fosses permanentes*, because that has been found to be the best way of ventilating these latter. But he recommends, at the same time, that open gratings be placed in the streets at regular intervals, communicating with the sewers. In Southampton, gratings in the road gave off such offensive effluvia that the inhabitants of the neighbouring houses stopped them up with pieces of wood, the result being that the gases forced themselves up through the imperfect traps into the houses.

Rendered less necessary by flushing,

In many towns there is no pretence made of ventilating the sewers, and it is certain that smooth pipe sewers, regularly flushed, are not likely to require as much ventilation as badly laid brick sewers, in which accumulation takes place and foul air is formed. Dr. Neil Arnott says (*First Report H. of T. C.*, vol. i. p. 66) that "flushing in defective drains would lessen the quantity of impure air produced in them, but would not free the town from the amount which is unavoidable." At Alnwick, where no special ventilating shafts and no means of causing a draft of air are provided, but where the sewers are flushed *daily*, it is found that no effluvia arise from them, scarcely any even when the manholes are opened; and that there is no evidence of deficient ventilation of the pipes, or escape of sewage gases into houses.

but not safe to have no ventilators.

It is certainly, however, not safe to leave the sewers without any proper means of ventilation, as, if by any chance the sewage gets backed up in them, gases accumulate and are forced into the streets and houses through the only available openings, the street gully-holes and house drains. This took place, for instance, at Worthing, where, after the dry summer and during the very wet autumn of 1865, the sewage filled the well into which it is received, and backed up the sewers, driving the foul air up through the traps of sinks and water-closets. Since that time, however, the sewers have been amply ventilated.

The results of some "Experiments on the Air in Sewers and Drains" are given in the Report of the British Association Sewage Committee for 1869-70. The specimens were collected from various street and house sewers, chiefly in the Paddington district, *during the month of August*, so that there was every probability of the air being as foul as possible. They were chemically examined by Dr. W. J. Russell, F.R.S.; the most impure air that was examined contained 0·51 volumes of carbonic acid, 20·7 of oxygen, and 78·79 of nitrogen, in 100 volumes; or, as compared with ordinary atmospheric air, the nitrogen was rather less in amount, the oxygen a little less, and the carbonic acid about twelve times as great. In so far as these constituents are concerned, this air was not very much more impure than that in many crowded rooms; but it is certain that these constituents of sewer air are not those which it is most important to examine, for another specimen taken from some which "was blowing up the drain at the time, and had a disagreeable smell," gave only 0·12 volumes of carbonic acid, and as much as 20·91 of oxygen, while it contained no "combustible gases."

Composition of air in sewers.

Dr. Russell also passed some of the sewer air "through plugs of clean cotton-wool, which had been heated from 110° to 120° C." in order that any spores or other mechanically suspended impurities might be arrested.

One specimen of the wool, through which about 5000 cubic inches of the sewer air had been transmitted, was put into distilled water with a little white sugar, to see if any germs, similar to those

Heisch's test.

lately described by Professor Heisch, would become visible. The liquid was examined in a week's time, but none of the germs found.—(*British Association Report*, 1870, p. 73.)

This experiment was repeated with some air from another sewer, with the same negative result. Only the smallest trace of ammonia was found on a careful examination, while no sulphuretted hydrogen could be detected.

"These experiments must be looked upon as simply tentative, but certainly indicate a purer air in these sewers than might have been anticipated."

Some of the plugs of cotton-wool through which the air from the different sewers had been passed were sent to Mr. M. C. Cooke to be examined microscopically.

Microscopic examination

"The results generally indicate comparative freedom from organic bodies," he reported; nevertheless, spores resembling those of several fungi, and filaments "greatly like the mycelium of some minute fungus," besides starch granules, fragments of cellular tissue, of the fibrils of feathers, etc., were found, especially in the specimen through which most air (7000 cubic inches) had been passed. In another plug through which 5000 cubic inches of air from the same sewer had been passed, "no fungi spores were detected," but it "was largely charged with minute cubic and rhombic crystals, which polarised well," so that it is very likely "that the same sewer would at different periods of the same day give a different result in the organisms with which the air is charged." (*Loc. cit.* pp. 74, 75.)

Air less impure than expected

The general result of these experiments, so far as they go, is certainly that the air in the sewers is much less impure than one would have expected; and it must be remembered that the air examined was taken from the drain-sewers of London in the middle of August (the mean temperature of the air in Marylebone during August 1870 was 62·8° Fahr., and the highest 85° Fahr.) But modern methods (Koch's and Pasteur's) of cultivating bacteria and fungi and their spores on peptone-gelatine, would probably show a much higher degree of impurity than that indicated by these experiments.

On p. 205 a statement is quoted from the Ninth Report of the Medical Officer of the Privy Council, to the effect that the sewers of Bristol, which are neither flushed nor ventilated, require neither the one nor the other. We find, however, from a paper read by Mr. Sneade Brown before the Social Science Association at Bristol in 1869, that sewer gases certainly found their way into houses, especially in the upper parts of Clifton. He speaks of being "startled by an irruption of sewer gases, which permeated the house with their faint sickly odour, and made themselves particularly perceptible when the kitchen range was heated."

Necessity of sewer ventilation.

Sewers should certainly be regularly flushed, unless the gradient is sufficient throughout their whole length to keep them free from deposit; but, as we have said on p. 210, it is not safe to leave them without ventilating shafts, even when they are flushed regularly.

Causes producing movements of air in sewers.

The following are some of the causes which produce movement of air in sewers, and which, consequently, render ventilation necessary:—(1) In autumn and winter the temperature inside a sewer is higher than that of the external air (average 7°), consequently the warmer sewer air tends to rise and be replaced by the inflowing colder air from outside. In summer the temperature of the sewer is, during the day, often lower (average 3°) than that of the external air. In spring the temperature inside and outside the sewer is often equal. (2) The passage of hot liquids from houses or manufactories into the sewers may cause a considerable rise in the temperature of the sewage, and consequently expansion of the air over it. (3) Variations in the flow of sewage compress the air or allow of its expansion: thus during the early part of the day, when the flow is greatest, air is expelled in large volumes from the sewers; later in the day, as the flow diminishes, the external air enters the sewers to supply the place of that expelled in the morning. (4) A sudden fall of barometrical pressure causes a large quantity of air and gases dissolved in the sewage to be given off. (5) Sudden variations in temperature of the external air produce rapid expansion or contraction of the sewer air, and a rise of temperature also favours decomposition in the sewage and the evolution of gases.

Openings into sewers reduce the pressure of air within.

If numerous openings from the external air be made into the crowns of sewers, the pressure of air within them will vary but little, and there will not at any time be sufficient pressure to force the traps on house drains and pipes. The openings will at times act as outlets for sewer air, and at other times as inlets for fresh air.

Air under pressure in sewers escapes into houses.

Air under pressure in sewers, if there be no ready means of exit by ventilating shafts, most readily finds a means of escape into houses connected with the sewer. The ordinary flap-valve at the point of entry of the house drain into the sewer offers little obstacle to the passage of air, and the warmth of the interior of the house will exert an aspirating action on the colder and heavier air of the sewer. The sewer air will then escape into the house through defective joints in the drain or soil-pipe, or through bell traps in the floor, or it may accumulate to a very considerable extent under the basement floor. It will probably also enter many rooms in the house through untrapped waste and overflow-pipes connected directly with the drain or soil-pipe. Contamination of drinking water in cisterns is in this way especially frequent and dangerous in its effects.

Ventilation of sewers by untrapped rain-water pipes.

The very common plan of ventilating sewers by means of untrapped rain-water pipes from the roofs of houses is extremely dangerous. These pipes are often very loosely jointed, and the air rising from the sewer will escape through every such joint, possibly into bedrooms; and in many cases the open head of the pipe is just beneath a dormer or attic window. During heavy rain the rush of water down these pipes will force the air of the drain into the interior of the house through trapped or untrapped openings.

Ventilation of sewers by soil-pipes.

In some towns ventilation of the sewers is effected by means of the soil-pipes of houses, these being carried up full bore above the ridge of the roof, clear of all chimneys, no trap and disconnecting chamber being allowed between the house-drain and sewer. This may be a good method in the case of such a town as Memphis, where the sewers are stoneware pipes and are laid between the backs of two rows of houses, for then the drains will not pass under the basements of the houses, and the entry of sewer air into the house may be prevented by trapping and disconnecting all waste and overflow-pipes, and substituting siphon gullies for bell traps. But in the case of houses which drain into sewers laid in the front streets, the drain must pass under the house, and with

Method objectionable in ordinary cases.

this method of sewer ventilation there would be constant risk of the escape of sewer air through defective joints into the interior of the house. In all such cases the house-drain should pass through a disconnecting chamber with an air inlet and be trapped before entering the sewer. There is still another objection to this method, and that is that during heavy rain, when ventilation is most required, the opening of the house-drain into the sewer might be covered by the height of flow of the sewage. Where there is a disconnecting trap between the house-drain and sewer, a ventilating pipe may be carried from the drain on the sewer side of the trap to the top of the house, and would be effective as a ventilator, except in times of heavy rain, as before said, if of sufficiently large size (4 or 5 inches), and if there were openings into the sewers from the street level to act as air inlets.

Ventilation by a special pipe beyond the disconnecting trap.

Connection with furnace chimneys of no avail.

Connecting the sewers with furnace chimneys has not been found of any avail, for although a great draught may be created in the sewer for a short distance, air will rush in through the nearest street openings, or the traps on house drains will be drawn, to supply air for that extracted by the furnace; and there is besides the risk of an explosion from ignition of coal gas which may accidentally find its way into the sewer, as happened at Southwark, where the sewers were connected with the furnaces of soap works. More air will be extracted from the shaft if made to open into the flue than if made to pass through the furnace of the factory.

Simplest method of ventilation.

The simplest method of ventilation is to carry up a shaft from the crown of the sewer to the surface of the street above, where it is covered by an iron grid.

The objection to this plan is that mud and gravel fall through the bars of the grid and form a deposit on the floor of the sewer, which has to be removed by hand labour or transported with the sewage by continual flushing. This objection can be overcome by placing a tray beneath the gratings, which catches the mud but allows the passage of air around it. This tray should be capable of being removed from the surface of the road. Objection.

A better plan is to combine a vertical manhole and ventilator. A ventilating shaft is sunk for some distance by the side of the manhole, openings being left between them for the passage of air. Mud and gravel are excluded from the sewer by falling to the bottom of the shaft, from which water passes by a pipe into the sewer beneath. The deposit of gravel and mud can be removed through the manhole by the scavenger. Ventilator and manhole combined.

Iron-wire baskets filled with small wood charcoal were formerly placed horizontally in the manhole for the purpose of filtering the air, but unless they are very frequently renewed they are found to be useless, for they become clogged and damp, and in this state obstruct all passage of air. As long as the charcoal remains dry it has considerable effect in oxidising organic vapours and deodorising sewer air, as shown by the fact that nitrates and ammoniacal compounds can be recovered from the used charcoal by distillation. The difficulty in connection with the use of charcoal in sewer ventilation is to prevent its getting wet from rain and moisture, and to dispose it in such a manner that while it causes no obstruction to the passage of air from the sewer, yet all escaping air shall be filtered through it. These charcoal filters, when in use, require Charcoal filters become rapidly useless, from liability to become wet.

recarbonising once every six weeks or two months.

Now discontinued.

On account of these objections their use has been nearly everywhere discontinued.

Ventilating openings required at frequent intervals.

The ventilating openings should be placed at intervals of 50 to 100 yards along the length of the sewer; some of them will act as inlets and others as outlets, and the sewer air will be rendered so dilute as to be inoffensive where escaping. Messrs. Rawlinson and Maccabe, in their Report on the sewerage of Dublin, recommended that for the 120 miles of sewers in the city there should be 500 side entrances or manholes, and 2400 main sewer ventilators, or about one ventilator every 90 yards. They also recommended that "at all steep gradients the sewers should be ramped, a sewer mouth-flap covering the sewer end delivering sewage from above; this flap will prevent sewage gases flowing to the higher parts of the city as at present." (*Report of the Royal Commission on the Sewerage and Drainage of the city of Dublin*, p. x.)

Tumbling-bay and flap-valve.

By ramping is meant the formation of a tumbling-bay, so that a flap-valve can be applied to the sewer delivering sewage from above; then the sewer air which, when warmer and therefore lighter than the external air, tends to pass up a sewer having a steep gradient to the higher levels meeting the flap, is forced to escape through the manhole and ventilating opening, which should be constructed over the tumbling-bay.

Prevents ascent of sewer air.

Ventilating openings in middle of roadway.

The ventilating openings being in the middle of the roadway where the air is constantly in motion, the escaping gases will be quickly diluted, and the openings themselves will be at the greatest possible distances from the fronts of houses. Therefore they should be placed in the greatest numbers in the wider streets, and their use somewhat restricted in the narrower courts and alleys, where there is little movement of air, ventilating shafts from the sewers being carried up above the houses instead.

Untrapped street gullies.

To ventilate the sewers by leaving the street gullies untrapped at the sides of the footway would be objectionable, for mud and grit would easily enter the sewers, and the escaping gases might be a cause of annoyance to foot passengers, and would find more ready entrance into the fronts of houses.

Archimedean screws are useless.

Archimedean screws surmounting the tops of ventilating shafts have not been found in any way to facilitate the passage of the outgoing air.

Ventilation necessary for pipe sewers.

In the separate system of drains and sewers as much ventilation is required for the pipe sewers as for the brick sewers of the combined system, and, as shown in the case of Memphis, the manholes which are necessary as points of entry to the pipes for the purpose of removing obstructions, may be also used as ventilating openings.

The importance of thoroughly ventilating pipe sewers is dwelt upon by Dr. Buchanan in his Report on an epidemic of enteric fever in Croydon in 1875. (Appendix to *Report M. O. P. C.* and *L. G. B.*, New Series, No. VII.)

Outbreak of enteric fever from entry of infected sewer air into houses from unventilated pipe sewers.

Dr. Buchanan considered that the outbreak was in great part due to the entry of infected sewer air into houses through untrapped drains and openings into the drains. The pipe sewers were of small size, 6 or 9 inches diameter, and were ventilated at distances of 150 to 250 yards by "petty openings," which were blocked by charcoal trays. He says :—

Where sewers are small and ill ventilated, they constitute perfectly sufficient means for the rapid distribution of fever infection; and places having such sewers may not only show fever rates maintained as high as before the sewers were made, but they may show as smart outbursts of fever as are witnessed where conveyance through water or milk is in question. Croydon itself, after it had made its sewers and before it attempted to ventilate them, had this experience. So in other instances that have come under my personal knowledge, fever has maintained itself after pipe sewers, ill ventilated, had been laid; as in Rugby, in Carlisle, in Chelmsford, in Penzance, in Worthing; in the last two places breaking out in severe, sudden, and diffused epidemics, without there being any question of other distribution than by sewers. And my personal knowledge is confirmed by that of others. Towns with larger sewers have not appeared to have the same suddenness of outbreak, when spread by means of sewer air has been in question. In them the evil influence of sewer infection is more gradually manifested, as might be expected, from the different physical circumstances of the two kinds of sewers. The intention of small sewers, as opposed to large ones, is that their contents shall flow away with great rapidity, leaving the sewer clean and free from deposit. So far as small sewers fail to fulfil this intention, they have certain disadvantages of their own. To some extent, when sewers are running freely, but greatly more when they are not running freely, displacement of air from them is an affair of sewer calibre. If a 6-inch sewer be not running well, and a pail of water be thrown into it, that water will occupy sixteen times the space relatively to the sewer diameter that it would occupy in a 2-feet sewer; displacement of air in the smaller sewer will be relatively sixteen times as great, and the displacement will be greatly more sudden. Hence the air in a small sewer is liable to be under far greater pressure than the air of a larger sewer. To afford a safe exit to displaced and compressed sewer air is one (the more popularly understood) object of sewer ventilation; and it is plain that means of such ventilation are wanted more numerously in proportion as the displacements of air may be local and sudden. For any want of perfect freedom of current and lack of proper exit-means for displaced air *tells for more* in small than in large sewers. But at least as important a further object to be attained by the ventilation of sewers, is such dilution of sewer air as shall reduce to the utmost its harmful qualities. These harmful qualities are popularly measured by smell; and if there be no sewer smell people think little of danger from a sewer. The popular view may be true enough of such minor harm as may come from ordinary excrement decomposition; but it is certainly not true of such greater harm as comes from the specific infection of a sewer. Croydon itself has given some of the experience upon which this judgment is founded. In those of its former fever epidemics, which could be indisputably associated with escape of sewer air into houses, the offensiveness of the sewer air has not been great, nothing nearly so great as at many a harmless street gully in London. It has even happened at Croydon and elsewhere that noise and not smell has been the means by which the escape of infected sewer air has been recognised. And increasing

Suddenness of outbreak.

Intention of small sewers.

Displacement of air is greater and more sudden in small than in large sewers.

Offensiveness no criterion of infectiveness of sewer-air.

knowledge of the nature of fever has made it pretty certain that the material of contagion is a substance itself without odour, and perhaps less likely to be active in excrement that has passed into fœtid decomposition. Thorough ventilation then, for the purpose of diluting and, as far as possible, nullifying the infection that infective sewage exhales, is wanted, equally whether the sewer stinks or does not stink. Want of due distinction between stink and infectiveness has led to this consideration being overlooked in practice; and it has repeatedly happened that the air of small sewers has possessed (to judge by results) an infectiveness more intense than the air of more offensive large sewers. The air in a 9-inch pipe, with petty openings at every 150 to 250 yards, and no other openings except the soil-pipes of houses, is liable, it appears to me, to contain in a very concentrated form the poison of enteric fever, if excrement from fever patients be discharged into the pipe anywhere in the neighbourhood. While I admit that, for the most part, the sewers of Croydon are well adapted for the removal of liquids and solids, they appear to me to be adapted, when infected by fever excrement, to facilitate the passage of infection into the vicinity of houses. The air of sewers is, as it were, "laid on" to houses; it is arranged that every house drain and every house soil-pipe shall contain, up to the very wall of the house and up to the very trap of the water closet, the common air of the Croydon sewers, not simply charged with impurities it may receive from the particular house, but charged also with any dangerous quality that it may have brought from other houses; for hardly anywhere in Croydon can there be found an arrangement for severing the sewer air from the air of the house drain. So that wherever drain air has entered a house, no matter by how inconspicuous a defect, and no matter whether it has given rise to stink or not, it has been the air of the common sewer, and this was throughout 1875 charged to an intense degree with the infection of enteric fever. (*Loc. cit.* pp. 47, 48.)

Air of sewers "laid on" to houses.

Dr. Buchanan's Report should teach the lesson that, in any scheme of sewerage, the subject of ventilation should receive the most earnest attention, as the health of the inhabitants and their freedom from infectious disease will to a great extent depend upon the efficiency with which sewer ventilation has been carried out.

Importance of ventilation.

A system of ventilating sewers by shafts has been introduced by Mr. G. F. Harrington of Ryde. In this system provision is made for the entry of air into the sewer by a shaft with a revolving cowl at its upper

Harrington's system of ventilating sewers.

end, so arranged that its mouth is always presented to the wind. Whenever the wind is blowing, air will enter through the cowl and descend through the shaft to the sewer, to be extracted at a varying distance of 300 to 500 feet, by a shaft which terminates above in an open end. The diameters of the shafts are proportioned to the diameters of the sewer to be ventilated. The shafts are constructed in brickwork and are built up the outsides of adjoining houses.

Useful for badly constructed sewers.

This system is likely to prove of use in the case of old or badly constructed sewers, especially if they have a dead end. In the case of such sewers, if the ventilation is carried on by gratings at the street level, complaint is often made of the offensive smells in the street, and the inhabitants put a stop to this by closing up the ventilators themselves.

Application in Chelsea.

That this system of ventilation can be made very effective is shown by the Report of Mr. G. R. Strachan, surveyor to the Chelsea Vestry. In a street in this parish 600 feet of egg-shaped brick sewer, 3 feet 9 inches by 2 feet 6 inches, were experimented on. The sewer at the highest part terminates in a dead end, while the lower end joins one of the main sewers, and at this point a siphon was constructed so as to confine the sewer air in the length stated. There are three depressions on the invert of the sewer in which solid sewage stagnates, and from which very offensive smells are given off. The house drains are connected to this sewer by block flap-traps. Near the centre of the length of the sewer a 15-inch pipe is inserted at springing-level, and is connected to a shaft by pipes of a similar diameter. The shaft is fixed against the side of the house opposite, and terminates in a lobster-backed cowl so arranged as to present its mouth to

Downcast shaft.

the wind. The cowl is 32 feet above the level of the street and is above the roof of the house. At the high end of the sewer a 12-inch pipe connects it with a shaft that is fixed against the house opposite, and which terminates with an open mouth above the roof, at a height of 22 feet above the level of the street. At the lower end of the sewer a similar arrangement exists, the height of the shaft being 31 feet above the level of the street. The air intercepted by the mouth of the cowl is forced down the shaft by the pressure of the wind, and so into the sewer, where it separates into two currents, one of which goes up the sewer to the pipe and shaft at the higher end, while the other goes down the sewer to the pipe and shaft at the lower end. The sewer is thus an elongated tube with a capacity of 4300 cubic feet, through which fresh air is passing from a downcast shaft in the centre, to escape by the upcast shafts at each end. By experiments extending over forty-four days it was found that air entered the sewer on an average at the rate of 140 cubic feet per minute, which would change the air in the sewer every thirty-one minutes or 46 times per day. Mr. Strachan found that if the velocity of the wind is multiplied into the area of the throat of the cowl, one-third of the theoretical volume that would pass through it, if there were no loss from friction, actually passed through the sewer. It was also observed that the effect of this passage of air through the sewer was to cause drying of its sides, the offensive slimy coating before present disappearing.

Upcast shafts.

Experiments on the change of air in the sewer.

The variations in pressure of the air in sewers caused by the discharge of large volumes of warm water from manufactories, and also by the discharge of hot water and steam from boilers, were investigated

Pressure of air in sewers.

by the late Professor Parkes and Dr. Burdon Sanderson, in the case of the sewers at Liverpool. (Report 1871, pp. 23-27). Their conclusions were that "the general effect of the constant discharge of warm water into a sewer is to increase the in-draught, by diminishing the tension of the air in its interior." This result being, in their opinion, "entirely dependent on the large quantity of water which is discharged, and the rapidity of its flow; for it is well known that in all sewers in which there is a strong and rapid stream, a current of air is produced which is in the same direction as the water stream, and is *cæteris paribus* of proportional velocity. In a word, the in-draught at the inlets is due to the down-draught in the sewer." They were therefore of opinion that—

Discharge of warm water into sewers.

The introduction of a large quantity of water into certain sewers which receive the drainage of manufactories, in addition to its obvious utility as a means of preventing deposit, may also be useful as regards ventilation, and that, if the flow is constant, the ventilating effect will not be interfered with by the temperature at which the water is discharged. They thought it not unreasonable to suppose that this benefit is likely to be overbalanced by the danger arising from the accelerated decomposition of the sewage, but in addition to this there is another ground of objection, . . . which is, in the present state of the sewers in Liverpool, of very great importance. They refer to the difficulty which the existence of warm water in the sewers puts in the way of frequent inspection. In consequence of the saturated condition of the air and the high temperature, no warm sewer can be entered unless it has been open to the air for some time previously; consequently no such sewer can be inspected without the expenditure of much time and labour in the preliminary preparations.

Useful for ventilation.

Hinders frequent inspection.

The "blowing off" of boilers into the public sewers Drs. Parkes and Sanderson considered to be so obviously improper that they supposed no one would be prepared to defend it.

Discharge of contents of boilers.

When a boiler is "blown off," its contents enter the sewer at a temperature not much below the boiling point. Consequently the pressure on the interior of the sewer suddenly rises, and the air, aqueous vapour, and gases it contains are forced out by the readiest outlet, *i.e.* into houses. . . . Although in a sewer which communicates freely with the air the effect of blowing off a single boiler must be of short duration, it can never be free from very serious objection. In the comparatively closed state of the Liverpool sewers the effect of the process must of course be much more serious.

Drs. Parkes and Sanderson also conducted some experiments on the pressure of air in sewers in which tidal flow occurs from the absence of tidal valves at the sewer outfall. They showed that "in consequence of the innumerable channels permeable to air by which the interior of a sewer communicates with the exterior, and the relative slowness with which the tide rises and falls, the displacement of air during flow, and its replacement during ebb has no appreciable influence. So far therefore as relates to ventilation, the closure of the outlets and the filling of certain of the sewers by the tide are matters which deserve no consideration." (*Loc. cit.* pp. 21-23.)

Pressure of air in sewers from rise and fall of tide.

We arrived at the same conclusion after examining the sewers leading from Londesborough Lodge, Scarborough, at the time of the illness of the Prince of Wales (Letter to the *Times*, 22d January 1872). "After a stormy night, when much water descended the sewers, and the tide was rising fast, and within about an hour of high tide, I could detect no escape of air at any of the openings that I examined, and in the crescent sewer in the Lodge garden the anemometer detected no draught at all; the up-draught during rising tide was always slight when there was one, and could be detected at the ventilator in the horse-stand below the entrance of the crescent sewer into the main; during the fall of the tide a slight up-draught was usually observed, which varied with the velocity of the wind."

Tide exerts little influence.

The Report of the Special Purposes and Sanitary Committee of the Metropolitan Board of Works, appointed in 1877 to inquire into the cleansing and ventilation of sewers, has recently (February 1886) appeared. From this Report we learn that the surface roadway ventilators to sewers in the metropolis are placed in the different districts at very variable distances apart, viz. from 17 yards to as much as 600 yards. The average distance apart is 120 yards. In other towns the distance apart of the ventilators varies from 30 yards to 200 yards, the usual distances being from 50 to 100 yards. The shafts built up from the crowns of the sewers are usually circular in shape and about 18 inches in diameter, with a superficial area for ventilation of 254·5 inches. The openings in the gratings, however, are very much smaller, varying in the different metropolitan districts from 27 up to 70 inches of superficial area. In considering how the ventilation of the metropolitan sewers, which in many districts is extremely defective, may be remedied, the Committee point out that reliance must be placed chiefly on increasing the number of surface ventilators, but with this may be combined, where possible, ventilation by means of pipes or shafts carried from the crown of the sewer to the side of the road, and thence up houses or buildings, clear away from all windows and chimneys. If these pipes are of sufficient size—6 inches or more in diameter—they will act principally as exits for foul air, whilst the surface ventilators will act as inlets for fresh air, and nuisance arising from the escape of sewer air in the streets would be to a great extent obviated. It would, however, be a great mistake to entirely substitute such pipe ventilation for the surface gratings, for apart from the fact that the efficiency of the ventilation is greatly impaired by the greater obstruc-

Ventilation of sewers in the metropolis.

How the ventilation may be improved.

Pipe ventilators may be combined with surface ventilators.

tion to the passage of air from bends and friction in the longer pipe or shaft, the warning that at present exists when a surface grating is giving off offensive gases that a collection or deposit of offensive matter exists in the sewer requiring removal, would be wanting. Unless, too, the ventilating pipes are placed with much care, there would be a danger of foul air entering houses through windows and chimneys.

Ventilation of sewers should be a public measure.

The ventilation of sewers is a measure necessary for the public health, and should be paid for out of the public rates, like any other measure necessary for the common good. It is not right nor is it desirable that the ventilation of public sewers should be effected through the drains and soil-pipes or rain-water pipes of private householders. Nor because the householder has disconnected his dwelling entirely from the air of the public sewer by means of a water-trap on the house drain before it enters the sewer, should he be compelled at his own expense to carry up a pipe from the sewer side of such trap to the roof of his house in order to ventilate the public sewer. If such a method of ventilation is necessary, it should be paid for out of the rates, in the same way and for the same reasons as the construction of sewers is so paid for.

Deodorisation of sewage in house drains and branch sewers.

During hot weather in summer the metropolitan sewers are very liable to offensive deposits owing to defective flushing. The Committee point out the difficulty in obtaining water at cheap rates from the water companies for flushing purposes, and suggest as an alternative the addition of deodorising substances to the sewage, both in house drains and small branch sewers, to prevent putrefaction and the evolution of gases. One to two grains of the crude manganate of soda, with about one-third that quantity of sulphuric acid to each gallon of sewage, has been found very effective by the Metropolitan Board of Works. Whether any effectual general deodorisation of the sewage of the metropolis could be in this manner attained without enormous expense, has yet to be proved by actual experiment.

COST OF SEWERS.

As examples of the cost of sewerage works we extract the following from the evidence procured by the Rivers Pollution Commissioners (*First Report*, 1868, vol. ii. p. 55, etc.) :—

Manchester sewerage.

At Manchester—where "efficient sewerage works have been carried out in all the streets within the city," the main outfall sewers being principally constructed of brickwork, and the smaller ones of glazed earthenware oval pipes, "the size of the brick sewers varying from 6 feet by 3 feet to 3 feet by 2 feet; and the pipe sewers from 25 inches by 18 inches to 12 inches by 9 inches," and there being altogether 63 main sewers of various lengths, making a sum total of 280 miles—the cost has been about £340,000. There is, however, here no special mode of ventilation provided, and no flushing apparatus required. At Blackburn—where "one outlet comprises a main sewer 6 feet by 4 feet, egg-shaped, with tributary main sewers from 4 feet 10 inches by 2 feet 8 inches, egg-shaped, to 2 feet diameter, all of brick, and pipe-sewers from 21 inches to 9 inches diameter; total length of main sewers 32 miles; subsidiary mains in back roads from 9 inches to 15 inches diameter, 19 miles"—the cost has been about £90,000. The ventilation here is by spouts from houses, by special

Blackburn: brick and pipe.

shafts opening at the surface of the streets and provided with charcoal ventilators, and by connection with three factory chimneys. No flushing is required, the fall of the sewers being considerable. At Preston, "$16\frac{1}{4}$ miles of stoneware pipes and $8\frac{3}{4}$ miles of brick sewers cost £50,000. Also 30 miles of stoneware pipe sewers, in streets paid for by owners, cost £9000." At Gorton, "the sewerage works comprise— Pipe sewers.

1408	yards	of 36-inch	brick	sewers.
1520	"	30 "	"	
980	"	24 "	"	
1165	"	18 by 27 "	"	
2634	"	15 "	pipe	sewers.
880	"	12 "	"	
1349	"	9 "	"	
3705	"	6 "	"	

together with gullies, traps, manholes and lampholes, at a total cost of £9579 : 11 : 9."

The above instances, taken at random, will give a better idea of the cost of constructing sewers than would be given by a list of the details of the cost of materials, work, and so forth. It may be noted as a general rule, that egg-shaped brick sewers, half a brick thick, are cheaper than pipe sewers, when the size is greater than 2 feet by 18 inches; but when less than this size, pipe sewers are cheaper.

A great outcry has been raised against the "separate" system on account of its expense. That it is more expensive to build two sets of sewers than one, when we require the drains to be deep enough to drain the subsoil and large enough to carry off storm waters, is plain enough; but that it is cheaper to make existing drain-sewers do their work properly (as far as this is possible) than to leave them to act as drains only, and to build a separate set of small pipe sewers for the house drainage, we cannot admit. "Separate system" expense.

And when we consider the danger that arises from the drain-sewers overflowing during heavy storms, flooding streets and cellars with diluted sewage, and forcing sewer gases up into houses, and on the other hand the impossibility at such times of any pretence at utilising the sewage, which must then inevitably be allowed to get to the rivers as best it can, and even the difficulty of dealing with it when only diluted with the ordinary rainfall and subsoil water, we must agree with Dr. Rolleston, who said in his article "Sewage and Sewerage" (*Quarterly Journal of Science,* April 1866), that the question of the separation of sewers from drains "does admit of two opinions being held about it;" but we must go farther than this, as we have good reason to believe that he afterwards did, and, looking at the great size of the outfall works and channels necessitated by the enormous volume of the diluted sewage, and the special disadvantages and extra expenses where irrigation is resorted to (and to which we shall refer again), we are driven to the conclusion that it would be *a very great saving* in the long run to a town to send its rain and subsoil water at once by deep drains into the nearest watercourse, and to construct special pipe sewers of very moderate dimensions to carry the house refuse away from the town to outfall works, there to be utilised in some way or other.

"Two opinions."

Great saving in the long run.

CONTINENTAL SYSTEMS OF SEWERAGE.

From a paper read at the Congress of the Sanitary Institute of Great Britain at Leicester in 1885, by Mr. J. Gordon, M. Inst. C.E., who has been connected with several of the principal sewerage schemes adopted in continental cities, we find that the chief towns on the Continent that have adopted the water-carriage system in its entirety are Berlin, Frankfort, Munich, Dantzic, Düsseldorf, Breslau, Linz, Hamburg, Brussels, and Rotterdam. In Stuttgart, Crefeld, Dortmund, Ludwigshäfen, Mannheim, Darmstadt, Heidelberg, Mayence, Basle, and Zurich, although new systems of sewers have either been constructed or are in course of construction, thoroughly and completely adapted to the water-carriage system, the authorities have not yet made up their minds to admit the drainage from water-closets into them. In these towns cesspools are still in use, and are emptied automatically on the pneumatic system. At Heidelberg, Nuremberg, Gratz, and Zurich, the tub system is in force; in the two former towns the urine is retained in the tub, whilst in the two latter it is allowed to pass into the sewers.

Drainage from water-closets not admitted.

In those towns that have adopted complete systems of sewerage, the sewers are invariably designed to accommodate the rainfall as well as the sewage of the town. Thus in Frankfort "a rainfall of $\frac{7}{8}$ inch in twenty-four hours has been provided for without bringing the storm overflows into action." In Dantzic "the tributary sewers are calculated to discharge a fall of $\frac{1}{2}$ inch per hour, the main trunk sewers (leading to the outfall) being relieved by storm overflows." In Berlin as much as $\frac{5}{16}$ inch of rain per hour has been provided for, whilst in Cologne the main trunk sewers are calculated to carry off $\frac{1}{2}$ inch, and the subsidiary sewers $1\frac{1}{5}$ inch per hour. The largest main sewer is, however, in this case, 8 feet 2 inches by 7 feet 3 inches, with a contracted channel for the dry weather flow and a small footpath on one side.

Sewers carry off the rain-fall.

In Frankfort, Munich, Stuttgart, and other towns with which Mr. Gordon was connected, the sewers have been laid deep enough to drain the basements and cellars of all houses. Dead ends to the sewers do not exist, "owing to the sewers being laid at such levels as to join them to each other at street ends, thus making it possible to flush the lateral sewers from the main trunk sewers by means of flushing gates and stops, without having recourse to supplementing the flushing power from the water-supply of the town; the system being, by this arrangement, to a large extent, interchangeable and self-balancing, no serious difficulty can possibly arise from any mishap in the way of a block, or in the case of one sewer being more surcharged than another, inasmuch as the branch sewers will always admit of the passage of the sewage or rainfall round a block, until it has been removed."

No dead ends to the sewers.

Blockages prevented.

In Dantzic, Breslau, and Berlin the sewers are chiefly pipes. In Berlin a sewer has been laid at each side of the street. By this means pipe sewers are sufficient where otherwise brick sewers would have been required, and the streets being wide the traffic in the centre of the street was not interfered with during the construction of the sewers, whilst the house-drains, being shortened in their course, could be laid at a steeper gradient than if the sewers were in the middle of the street. Brick sewers were also found to be very difficult to construct water-tight in Berlin, owing to the subsoil being surcharged with water and consisting of fine running sand. None of the sewers in Berlin are laid at a steeper gradient than 1 in 500, and this is accomplished by carrying the branch pipe sewers into the manholes on the main sewers at varying depths above the invert of the manhole. The reason of this limit being adopted is the theory of the engineer, Mr.

Pipe sewers laid on both sides of the street.

Steep gradients not allowed.

Hobrecht, that "with branch sewers of steep gradients a state of things is involved in which, during the night, and also with the minimum day flow, so small a portion of the invert of the sewer or pipe is covered by the flowing sewage as to leave a large portion of the sides of the pipe covered with slimy matter, exposed to the action of the comparatively high temperature of the sewer." This slimy matter, in his opinion, soon dries and gives off pungent gases. He also thinks that steep branch sewers tend to run dry and deposit solid matters on the sides of the pipes, which are not always subsequently washed onwards. The sewers of Frankfort, Crefeld, Mayence, and Düsseldorf are mainly of brick, whilst those of Mannheim, Heidelberg, and of nearly all the Swiss towns, are of cement concrete. Reasons. Materials of sewers.

The sewers in most of these towns are ventilated by surface gratings in the centres of the roads, about 40 yards apart, and the street gullies are trapped. These gratings act chiefly as inlets for fresh air, the outlets being the soil-pipes and rain-water pipes of the houses, for disconnection of the house drains from the sewers is not practised. In Frankfort the soil-pipes are of cast-iron, varnished inside and outside with Dr. Angus Smith's patent varnish, and jointed with lead. They are carried through the roofs of the houses with the tops left open. The use of these varnished cast-iron pipes is also made imperative for drains and waste-pipes from sinks. Disconnection of waste-pipes is not insisted on, owing to the severity of the weather in winter rendering the use of siphon gullies outside the house impracticable; but all waste-pipes are made to extend up above the roof and left open like the soil-pipes, a matter easily accomplished, as the houses are chiefly on the flat system, and the Ventilation of sewers by road gratings and by house pipes.

sinks and baths, etc. are generally in tiers one above another. "Duplicate copies of every house drain plan with sections of every branch and tier of closets or sinks, showing every junction-pipe and connection to a scale of 10 feet to the inch, are deposited with the authorities, and these plans, showing the gradients and depths of the drains with the interior arrangements of the house, are again transferred to the town plans, drawn to a scale of $\frac{1}{250}$ natural size or about 20 feet to the inch, so that the authorities are in possession of a set of plans, entirely unknown, the author believes, to any English or other municipality outside the confines of the German Empire."

Plans of house drainage.

THE SHONE SYSTEM.

Raising sewage by compressed air.

This is a method of raising sewage by means of compressed air, and is intended for the use of towns situated on low-lying level ground, where the gradients obtainable for gravitating sewers are small, or for towns where the sewage has to be pumped to the outfalls.

The air is compressed at a station at any place in or outside of the town, and is conveyed by 2-inch wrought-iron pipes to the "ejectors," of which there may be several at different parts of the town, situated in chambers below the surface of the streets. The ejector receives the sewage of a number of houses from the street sewer; its size depends upon the amount and the rate of maximum flow of the sewage it is required to receive. Thus the ejector in use at Wrexham has a capacity of 325 gallons, and serves a population of 1920 people, with a daily sewage discharge of 57,600 gallons (30 gallons per head daily). If the rate of maximum flow is taken at half this quantity in

400 minutes, then the ejector would during this period take $4\frac{1}{2}$ minutes to fill and discharge, while during the remainder of the day it would take about $11\frac{1}{2}$ minutes. This ejector is spherical in shape, 5 feet in diameter, and made of cast-iron; its action in filling and discharging is rendered automatic by the following apparatus:—The inlet and outlet pipes are provided with ball valves, which only allow the sewage to pass one way. Inside the ejector is a cup connected by a rod with an inverted cup above, and with a lever which is attached to a slide-valve arrangement, for opening and closing the "compressed air" and "escape" pipes. The weight of the cups and rod is partially balanced by a weight on the other arm of the lever. When the sewage enters the ejector, the lower cup becomes filled with the liquid, which rises also above it, and it then loses weight equal to the weight of water displaced; the sewage rises to the top of the ejector, and gradually compressing the air in the inverted cup forces this with the rod attached to it upwards, thus raising the arm of the lever and closing by the slide-valve arrangement the opening into the escape-pipe, whilst opening the compressed air-pipe. The compressed air then enters the ejector, and forces the sewage out through the discharge-pipe. When the ejector is emptied to the discharging line, the lower cup falls by its own weight, the lever is depressed, and the slide-valve closes the compressed air and opens the escape-pipe, the compressed air in the ejector escaping through this pipe into the manhole or chamber above. If the air is compressed to the extent of 15 lbs. to the square inch (one atmosphere), the sewage will be raised to the height of 34 feet in the discharge-pipe.

Ejectors filled and discharged automatically.

The sewage may be raised at once by the ejector

Sewage may be raised into a "sealed" sewer.

into an ordinary gravitating sewer, or into a "sealed" sewer of cast-iron pipes, when it is necessary that the rise should be more gradual and continued over a greater distance. The ejector is placed at such a depth in the soil as to permit of the house drains and street sewers being laid at good gradients, the sewage entering the ejector by gravitation.

Siphon flush-tank.

Mr. Shone, the inventor, has also designed a siphon flush-tank, to be placed at the head of each house drain to receive the soil and house waste-pipes; the siphon being started by the fall of water from a tumbling-box into the tank.

Advantages claimed for the system.

The advantages claimed by the inventor for his system are stated by him to be:—

1. That compressed air is a motor that can be conveyed and divided amongst any number of stations near to or far apart from each other, without any appreciable loss either by leakage in the pipes, if properly laid and jointed, or by friction; the only loss being that due to clearance of compressed air from the ejectors when discharged.

2. As compared with steam, compressed air is unobjectionable, on account of the absence of heat radiating from the pipes conveying it; the temperature of the air conveyed being nearly the same as that of the outside atmosphere.

3. The air can be compressed at one station, so that one staff only is required, as in the case of a single outfall; and as the position of this station is immaterial, the air compressing machinery may be fixed at a point where the local authorities have already other engines at work.

4. As good gradients may be given to the sewers, the sewage is carried to the ejectors and forced out of the town in a fresh and undecomposed state.

5. No storage is required as in ordinary pumping, where the rate of flow of the sewage may exceed the powers of the machinery; for the rate of working of the ejector varies with the rate of flow of the sewage, although the rate of working of the machinery for air compressing is nearly uniform. When the ejectors are working slowly, the tension of air in .the air mains will be raised, to fall as soon as the ejectors begin to work more rapidly.

6. Up to lifts of above 60 feet, it would seem that forcing by compressed air is more economical than direct pumping, while if the pumping machinery is of small capacity, the economy is likely to extend even beyond this height.

Shone's system is in operation at Eastbourne, Wrexham, Southampton, Warrington, and Henley, and is now being applied at the Houses of Parliament, where the existing outfall sewer is below the level of the metropolitan main sewer, so that sewage is constantly backed up in it, converting it into an elongated cesspool. The nuisance that has resulted in the Houses from the defective sewerage arrangements is well known. Three ejectors—one of 500 and two each of 300 gallons capacity are now being erected in an underground chamber in Speaker's Green. These will be supplied with compressed air from four gas engines, each of 4 horse-power, and will be capable, in combination, of discharging 1200 gallons per minute into the metropolitan main sewer. It is estimated that one 300 gallon ejector and one gas engine will be sufficient at ordinary times for the discharge of the sewage, the other ejectors being put into action, as required, during periods of rainfall—the rainfall over a surface of about 8 acres being provided for. The outfall sewer leading to the ejectors is to be a 12-inch iron pipe laid on the invert of the existing brick sewer, and smaller iron pipes will also be laid in the subsidiary brick sewers. These pipes will be flushed by siphon-action cisterns, and arrangements are being made for ventilating the new pipe sewers and the subways (the old brick sewers) in which they are laid, by extracting the air from them (as well as that escaping from the ejectors), by means of the furnace in the Victoria Tower.

Applied at the Houses of Parliament.

THE LIERNUR SYSTEM.

In this system, as devised by its inventor, there are two separate sets of drains; the one devoted exclus-

Two sets of drains.

ively to the evacuation of household waste water, rain water, and waste liquids from factories; the other to fæcal matters from *cabinets d'aisance* without water supply, and from water-closets, as well as bedroom slops.

Rain and waste waters filtered.

The first system of drains is intended to receive the rain and waste waters only after all solid matters of even the smallest size have been separated from them by filtration, and the waste liquids from factories and workshops only after efficient purification in their own premises. The inventor is of opinion that the contents of these drains, from which fæcal matters, urine, the solid waste from kitchens and factories and the mud of the streets are excluded, might be allowed to flow at once and at any part of the town into a stream or river, for these waste waters would only contain 1 to 4 parts of nitrogen in a million parts, and would be quite innocuous. The inventor is also of opinion that on account of the separation of the solid matters, the stoneware pipes used for this purpose might be made of much smaller dimensions than would be considered necessary by English engineers, who think that the exclusion of solid matters has not much influence on the volume of the sewage. With this view, and to aid in the flushing of these drains, which might (in Holland) have to be constructed with very small gradients, rain water is admitted by means of vertical funnels, which throw a concentrated jet of water in the direction of the current. The town of Amsterdam has adopted pipes of small diameter for the waste waters with great success, but without any such means of filtration alluded to above; and this appears to be unnecessary, for the drains are short, and open everywhere into the canals. For greater lengths of pipe filtration would be necessary. For

Allowed to flow at once into a stream.

Pipes may be smaller.

Waste waters not filtered in Amsterdam.

this purpose all kitchen sinks are furnished with an iron strainer the bars of the strainer being only half a millimetre apart. Solid matters retained by the strainer have to be thrown into the *cabinets*. To exclude mud from the drains, the water which passes through the street gullies is filtered through wire gauze filters placed in buckets. The buckets can be raised, when full of mud, and emptied into carts.

Same pipes may carry away subsoil water.

Captain Liernur believes that these pipes would also serve to carry away subsoil water, when this had risen above its normal level.

"Air-closets."

As regards the disposal of the sewage proper, the better classes may be supplied with water-closets, while for the lower and working classes "air-closets," without water supply, are preferable, as they are stronger and require less frequent repairs. When these air-closets are well constructed, they are perfectly inodorous, and in Amsterdam are placed without hesitation inside houses, without the least communication with the outside air, except by a small ventilating-pipe; and they are even built sometimes within kitchens. If by chance one does give rise to smell, it is due to a fault in one of the joints, which can easily be repaired. This seldom happens when the air-closet is originally constructed with care.

"Air-closets" inodorous.

Daily volume of sewage per head.

The experience of some years has shown that with these air-closets the daily volume of sewage for each person is 2½ litres, or 900 litres yearly. With the water-closets, the yearly volume for each person is about 2600 litres, and supposing that in a town the number of water-closets and air-closets is equal (a very liberal proportion for the water-closets), the average yearly volume of sewage for each person will be 1750 litres.

Description of air-closet.

The air-closet consists of a cast-iron hopper terminating in a siphon trap. The hopper has a lid, and just below this is the opening of a ventilating-pipe, which is carried up above the roof. The soil-pipe, which is of cast-iron, 5 inches in diameter, is trapped at the bottom by a siphon bend, and is also carried up above the roof, but of diminished capacity, 2 inches in diameter, a charcoal filter being inserted at the junction of the smaller with the larger pipe. The water-closet is on the same principle, but contains a small pan for holding water, near the top of the hopper, worked by an automatic apparatus, the contents of the pan being thrown on to the water in the siphon trap.

Soil-pipe.

Water-closet.

The soil-pipes open into a branch sewer-pipe, which is another 5-inch cast-iron pipe with gas-tight joints. This branch sewer-pipe is laid in lengths of long downward slopes of 1 in 250, and short upward slopes of 1 in 5, forming inverted siphons, where the sewage matters rest at varying heights according to the volume of sewage in the pipe. The branch sewer-pipes join the street sewer, which is also a 5-inch pipe, and varies in length from 100 to 800 metres. The street sewer-pipes are connected with cylindrical iron reservoirs, which are placed below the pavement in the centre of a district of 15 to 40 acres, the town being divided into these districts. At the junction with the reservoir is a valve which can shut off or open communication between the sewer-pipe and reservoir. The reservoir is connected with the works outside the town, where air vacuum pumps are worked by machinery by two sets of pipes; one set, having a diameter of 125 millimetres, serves exclusively for the movement of air, and is attached to the top of the street reservoir; the other set, of rather larger size,

Branch sewer-pipes form inverted siphons.

Street reservoir.

Two sets of vacuum-pipes.

passes to the bottom of the reservoir, and serves for the transport of the sewage to the works. Each set is provided with a valve at its junction with the street reservoir.

The method of working is as follows:—a vacuum being produced in the first set of pipes by the machinery at the works, this is communicated to the street reservoir by opening the valve for a few seconds, and then closing it. The valve on the street sewer pipe is next opened, causing air to enter the soil-pipes from the openings above the roofs of the houses, which carries before it the sewage into the street reservoir. All the closets and pipes connected with the sewer will empty themselves simultaneously by reason of the siphon arrangement of the branch sewer-pipes previously described. In those branch pipes that are full, the sewage will stand up to the top of the bend of the siphon, and will consequently be more easily drawn away than those which are less full, and in which the sewage has to pass up a greater length of the bend. As soon as the levels of sewage in the siphons of all the branch pipes are the same, they are all emptied equally until bubbles begin to pass, when no more sewage flows, leaving the pipes still trapped. Eighty branch pipes from houses can be emptied in this way at once. After a few minutes the valve at the street reservoir is turned off.

Method of working.

Closets and pipes emptied simultaneously.

Branch sewer-pipes left trapped.

As soon as the street reservoir is nearly full, air is admitted, and then the valve on the vacuum pipe serving for the transport of the sewage is turned, and the sewage is forced by atmospheric pressure into a large reservoir at the works. The sewage is then strained to separate the larger solid bodies, mixed with 1 per cent of sulphuric acid to retard fermentation and

Sewage carried to the works.

fix the ammonia, and heated to 100° C. in hot-air machines, when it becomes thick like treacle. It can be further dried in revolving copper cylinders to form a dry powder. This powder has a commercial value little short of Peruvian guano. All vapours and gases produced in drying, and the air from the exhaust pumps, are passed through the furnace, and driven by steam jet up the factory chimney.

Sewage converted into a dry manure.

Cost of the system.

As to the financial results, it is calculated that the yearly cost per head of the population will be 6 francs, this including the cost of evaporation of 1750 litres of water from the sewage of each person, 5 per cent interest on capital, costs of service, etc. The analysis of the poudrette gives 7·5 to 8 per cent of nitrogen, and 2·5 to 3 per cent of phosphoric acid. This will give a commercial value of 8 francs for 50 kilogs., which is the amount produced per head per annum. This leaves 2 francs per head as profit. The poudrette finds a ready market.—(Discours prononcé a l'Hotel de Ville d'Amsterdam le 28 Février 1883, à la Commission du Conseil Municipal de Paris, par C. M. de Bruyn Kops, ingénieur.)

Value of the manure.

Working at Amsterdam.

On personally inspecting the working of this system at Amsterdam, we found that the process of drawing the sewage into the reservoirs, and from them to the works, was conducted with the greatest facility, and without the production of any offensive odour; and that the closets in the houses, even of the poorest classes, without any water supply, often leading directly out of the living room, and without any means of ventilation other than the exhaust-pipe from the closet basin, were in every instance, although visited quite at haphazard, perfectly inoffensive.

There was no foul smell observable at the works, and the whole system appeared to be carried out without any nuisance arising at any of its stages. There can be no doubt that the system is well adapted for flat towns intersected with numerous canals, such as are to be found in Holland, where sewerage by gravitation presents great difficulties. As regards the value of the manure, we know that in any system, such as Liernur's, there is a great probability of some or even a large portion of the urine being carried off by the waste-water drains instead of by the proper channels. This would mean the deprivation from the manure of some of its most valuable ingredients, with a consequent reduction in the value estimated, as if it contained all the excretal refuse of the population. There would also probably be a greater dilution of the excreta with water than that given in the foregoing account. The cost of evaporation of a larger quantity of water would also mean a reduction in profits from the sale of the manufactured manure.

System carried on without nuisance.

Value of the manure.

THE BERLIER SYSTEM.

This system is very similar in principle to that of Liernur. The house drains are connected with iron pipes, in which a partial vacuum is maintained by means of an air-pump, so that the sewage is conveyed away from the houses by pneumatic pressure to the pumping station, which may be outside the town.

System similar to Liernur's.

From a descriptive pamphlet of this system by Mr. Adolphe Smith, F.C.S., we find that M. Berlier submitted a scheme for the drainage of Paris to the Municipal Council of that city in 1881, and was authorised to make experiments in the district extending from Levallois-Perret to the Madelaine.

Partial adoption in Paris.

Levallois-Perret is a suburb to the north-west of Paris, outside the fortifications, and here M. Berlier established his pumping station. The iron pipes were placed on ledges in the main sewers, and where necessary these pipes were siphoned to pass under obstacles lying in the way. The joints connecting the pipes are made with lead and are perfectly gas-tight. In the main sewers the pipes are 6 inches in diameter, but those that run up the neighbouring streets are only 4 inches in diameter.

Iron-pipes to convey the sewage.

The connection between these pipes and the house pipes is made as follows:—the soil-pipe, which in Paris is usually of large size—six or eight inches in diameter—opens at its foot into a rectangular-shaped iron vessel called a *receiver*. Within this receptacle is an iron wire-work circular basket, open at the top, considerably smaller than the *receiver*, and with the wires rather more than an inch apart. All hard substances and foreign bodies are retained in this basket. Once a week a man in the employ of the administration visits these *receivers*, and by means of a handle, fixed from the outside, imparts to the basket a violent rotary motion. The presence of any foreign heavy body is at once detected by the noise it makes when the basket is set in motion. The *receiver* can then at once be opened, and the foreign body withdrawn. Any fragile though somewhat hard substance, when beaten about by the motion of the basket, is soon sufficiently broken up to pass through the wire-work that surrounds it. Hence, whatever leaves the basket is in a fit condition to travel along the iron pipes without giving rise to any danger of obstruction, this being the sole purpose and function of the *receiver*. A modification of this

The *receiver*.

Retains foreign substances.

Hard but fragile matter broken up.

receiver has lately been introduced, the rotating basket being replaced by a wire strainer at the bottom of the receptacle, with verticle rotatory beaters above, but the principle in either case is the same.

From the bottom of the receiver a pipe serves to convey the sewage away to a second apparatus called the *evacuator*, which serves to disconnect the house from the public sewer. It may be placed side by side with the *receiver*, is also made of iron, and of about the same size, though circular in shape, and, like it also, is quite air-tight. The night-soil, rendered liquid by its passage through the wire-work basket, runs by gravitation into the *evacuator*, in which is placed a large ovoid float with its broad end uppermost, and its lower pointed end armed with an india-rubber valve that fits hermetically the opening at the bottom of the evacuator. This opening communicates with the pipes in which the partial vacuum is maintained, and the pneumatic suction helps to maintain the float firmly fixed and drawn down upon the mouth of the apparatus. When, however, a sufficient quantity of liquid has accumulated in the *evacuator*, the buoyancy of the float proves stronger than the downward suction. Disengaging itself, the float springs upwards, and the pneumatic suction, now acting on the liquids, rapidly draws them away. The difference of pressure of atmosphere between the interior of the pipes and the *evacuator* is sufficient to ensure the prompt removal of all the liquid. When no longer supported by the water the float falls back on the aperture without allowing any passage of air. This operation renews itself automatically each time the liquid reaches the floating line of the apparatus.

The *evacuator*.

Ovoid float.

Empties automatically.

The sewage is found to travel along the iron pipes with great facility. The vacuum to be maintained in these pipes need not exceed a pressure of 6 inches of mercury. "During the whole of the journey the semi-solids are held in suspension, as if something was constantly stirring up the water inside the pipes. This peculiarity has the appearance of ebullition, and is produced by the movement of the air within the pipes as it is drawn forwards by the pump at the works. The reduction of pressure also produces a certain amount of evaporation. The sewage being charged with gas that bubbles up and keeps all the more or less heavy matter in suspension, it is readily carried along, and does not adhere to the sides of the tubes."

Semi-solids held in suspension.

Sewage readily carried along.

The automatic action of the *evacuator* is the special feature of the Berlier system, and is, as will be readily seen, a great improvement on the Liernur plan, in which the pipes and the receivers can only be emptied by the opening of valves by hand. If, however, this system is extended in Paris or adopted elsewhere, we are of opinion that it will be found desirable to introduce the series of inverted siphons, as described under the Liernur system (see p. 240), otherwise it will be found impossible to maintain pneumatic suction in pipes at a distance from the pumping station.

Automatic action a special feature

Plan of inverted siphons.

In the district of Paris where the Berlier system is now adopted, the cesspools in the basements of the houses have been abolished, and as the closets only of these houses have been connected with the pneumatic system of pipes, the kitchen sink and other waste waters find their way into the ordinary sewers. The sewers of Paris are totally unfit to receive excremental or waste refuse of any kind, owing to their construction, their large size and absence of fall and of self-cleansing properties. Flushing is impossible,

Sewers of Paris unfit to receive excretal or waste refuse.

and a large army of sewer men are continually employed in removing deposits. It would therefore be desirable to convey away all the waste house waters by the pneumatic system of sewerage, wherever this is adopted, and to leave to the existing sewers the task of removing rain and subsoil waters for which only they are fitted. The very much smaller quantity of water used for all domestic purposes in Paris than in towns in this country, would render this feat by no means difficult of accomplishment.

Small amount of water used.

There can be no doubt that the Berlier system has proved of great sanitary advantage in that district of Paris in which it has been adopted. The huge cesspools in the basements or courtyards have been cleared or filled up, and a constant source of danger thus removed, and it is a noteworthy fact that the thousand soldiers in the barracks of the Pépinière, situated in that district, were the only troops in Paris which escaped the wide-spread typhoid fever epidemic of 1883. A system which is automatic in its working, which can be controlled by the sanitary authority, and which leaves nothing to individual initiative, is likely to prove most advantageous to the public health, at any rate as a substitute for large cesspools under the houses. It is unfortunate that the existing sewers in Paris are so entirely unsuited to the water-carriage system of excrement removal, and until the city is provided with sewers constructed on modern principles, excretal refuse must be retained in the vicinity of houses in cesspools, or in some form of midden pit or dry closet, unless it be removed by Berlier's or some other system not depending on gravitation as a motive power.

Sanitary advantage of the system.

System suitable to Paris.

Retention in houses of excretal refuse.

CHAPTER VII

SANITARY ASPECTS OF THE WATER-CARRIAGE SYSTEM

We have already given ample evidence to show that the prevalence of sickness in general, and of fevers (especially typhoid) in particular, accompanies the non-removal of excreta and other refuse matters from the neighbourhood of dwelling houses: it now remains for us to see whether any definite amelioration in this respect has taken place since a more efficient removal of such refuse matters has been provided for a great many towns by considerable improvements in the drains and sewers, and by the more general introduction of water-closets; and, if so, in what this amelioration consists. Happily, plenty of information is afforded us on this head by Dr. Buchanan's researches on the "results which have hitherto been gained in various parts of England by works and regulations designed to promote the public health" (*Ninth Report of the Medical Officer of the Privy Council*). In twenty-five towns where such works have been carried on, and many of which have been already referred to several times in these pages, in almost every case the general death-rate has been lowered, and in many instances considerably so. At Cardiff, for instance, it has been reduced from 332 to

Has efficient sewerage been a sanitary benefit?

General death-rate lowered.

226 per 10,000, equivalent to a reduction of 32 per cent (or, allowing for cholera, of 24 per cent). At Newport (in Monmouthshire) the reduction has been from 318 to 216, equivalent to 32 per cent (or, allowing for cholera and dysentery, to 23 per cent), and in each of these cases the reduction has taken place under each separate head of disease, with the single exception of scarlatina, which has increased 90 per cent at Cardiff and 18 per cent at Newport. The mortality of children under one year has been also remarkably lowered in these two places to the extent of 22 per cent at Cardiff and 21 per cent at Newport. At Merthyr Tydfil, too, the total reduction has been from 332 to 262, that is, 21 per cent (or, allowing for cholera, $12\frac{1}{2}$ per cent). Here the reduction in the case of children under one year old has been 24 per cent, although the deaths from lung diseases in infants have increased 16 per cent. Scarlatina, too, shows an increased mortality of 60 per cent. It will be noted that at each of the above places there has been thorough sewerage by *large* sewers, besides improvements in other ways, especially in the substitution of water-closets for privies, and in the supply of better water. At Macclesfield, where pipe sewers have been added to the old system, the midden system having been retained, but "reduced to its minimum of offensiveness," the reduction in the total of deaths has been 20 per cent; that of infants under a year old 23 per cent, although the deaths from lung diseases have increased 14 per cent; and scarlatina—unlike the preceding cases—has decreased 45 per cent. At Croydon, where the general mortality has decreased 20 per cent, the mortality of infants under

Influence on mortality of children.

Large drain-sewers.

"Separate" system.

one year old has increased 10 per cent. It is said of this that the altered circumstances of the town have brought about a largely increased birth-rate.

No *special* influence on child-mortality in any case.

The general result is, that "of special influence, either in amount or kind, exerted by sanitary works upon children under one year of age, different from that exerted upon the total population, no evidence whatever has been obtained." (*Loc. cit.* p. 42.)

Measles,

Under the heading of *measles* we find that its mortality has been in many cases considerably diminished, as at Bristol, Leicester, Croydon, Penzance, Ely, and other places. Elsewhere, however, it has in several instances considerably increased, as at Cheltenham, Dover, Warwick, Banbury, and Stratford-on-Avon. This may be in some cases accounted for by the increased density of the population: "the introduction of better drinking water has not perceptibly affected the prevalence of measles" (p. 43).

whooping-cough,

and scarlatina,

not connected with sewerage arrangements at all.

Of *whooping-cough*, and also of *scarlatina*, much the same must be said, "though, if South Wales be excluded, which has latterly been swept by a scarlatina epidemic that no sanitary influence has been able to resist, there does appear some probable connection between reduced prevalence of scarlatina and diminished crowding in houses;" although the fevers above mentioned have been more prevalent in some towns since the sanitary improvements have been made, they have been less so in others, and in fact they do not appear to be in any way connected with sewerage arrangements.

Croup and diphtheria, higher mortality.

The number of deaths from *croup* and *diphtheria* have in almost all the towns increased during or after the completion of their sanitary works, and in many cases diphtheria would seem to have appeared during these alterations and to have increased after them; thus, at Banbury, the mortality during the execution of the drainage and sewerage works rose from 0 to $\frac{1}{3}$.* During eight years after the completion of these works it was $1\frac{3}{4}$. At Chelmsford, diphtheria only appeared after the execution of the works, and reached a mortality of $6\frac{1}{3}$. At Ely the same was the case—the mortality reached $3\frac{2}{3}$; and at Dover a mortality of $3\frac{1}{2}$ was noted nine years after the execution of the sanitary works; "what might be anticipated from the free communication of the town with places in France where diphtheria prevailed early and severely." Newport is indeed the only place in which this disease, although appearing for the first time during the works, decreased considerably after their completion. Here croup remained almost unchanged in its death-rate.

Typhoid fever: enormous reduction in mortality.

But it is especially in the case of *typhoid fever* that important results have been obtained from the sanitary improvements. At no less than nine towns the diminution in the number of deaths has exceeded one-half, reaching at Salisbury 75 per cent. At ten towns the reduction has been between one-third and one-half; Bristol, with a reduction of 33 per cent, being at the bottom of this list. At Rugby the reduction has been 10 per cent; at Carlisle only 2 per cent; but at the former place the water supply until lately has not been good, and the sewers have only been flushed since 1863, before which it is stated that they "frequently got choked and had to be opened, poked clear with rods, and then washed out" (p. 168); and at Carlisle it is stated that "away from business quarters of the town, and yet not in the suburbs, there remain a number of courts and yards

Causes preventing reduction in some places.

* Per 10,000 of the population.

which are full of nuisances, and keep up the memory of what the whole town was in 1849" (p. 108). But it must be mentioned that at Chelmsford and Penzance there has been a slight increase (5 and 6 per cent respectively) in the death-rate of typhoid fever; while at Worthing there has been an increase of no less than 23 per cent. At Chelmsford, however, "the sewage is delivered into a tank by an outfall sewer which enters some six feet below ground" (p. 45): the result is, that although the opening can be covered with a sluice, and although a storm-water overflow is provided, it is a fact that when the engine is not at work or the liquid accumulates in the well, cellars get flooded by the sewage, and doubtless sewer gases get forced up into houses. With regard to Worthing, we have already remarked on the absence of any provision for ventilation, and on the fact that sewer gases had been forced up into houses through the traps of sinks and water-closets. That this was the cause of the outbreak of fever in 1865 "appears to reach positive demonstration when it is added that the fever almost exclusively attacked well-to-do houses on the higher levels, where the water-closets were inside the houses, and almost entirely spared the houses, mostly of a much poorer sort, situated on lower levels, where the closet was placed outside the house. It was not so in the times of cesspools; then, these low-lying poor houses were far more attacked with fever than the others. Moreover the fever subsided as soon as openings were made into the sewers, from certain houses where it before maintained itself for months" (p. 45). It must especially be noted that in Rugby, Carlisle, Chelmsford, and Worthing, the "sewage is received into pumping works at the outfall in such a way

Cases of increased mortality of typhoid fever.

Want of proper ventilation of sewers.

Evil due to outfall being low down in tanks.

that sewer gases are necessarily much confined in the pipes" (p. 45). In Leicester, too, the sewage, properly so called, is received in a pumping tank; but then Leicester has a separate system of storm sewers, so that there is much less chance of the liquid being backed up by the accumulation in the well.

In Morpeth, where the outfall of the sewer is not into a tank, but where, in many places, the pipe-sewers themselves are below the level of the river, "it happens that in times of flood the sewage is backed up the main sewer for four to five hundred yards" (p. 200). It appears that "occasional outbreaks of typhoid had followed times of flood when the outfall sewer had been under water" (p. 46).

Typhoid from backing up of sewage.

"Many of the public improvements have coincided with reduction of typhoid. . . . It is, however, the purification of atmosphere from decomposing organic matters, that has been most uniformly followed by a fall in the prevalence of typhoid. And this has occurred equally whether the purification has been brought about by the abolition of cesspools or by draining and drying 'middens'" (p. 44).

Chief cause of decrease.

The mortality from *diarrhœa* has been greatly reduced in many towns where sanitary improvements have been effected, but this reduction is by no means so universal as in the case of typhoid fever, the mortality having in many cases considerably increased.

Diarrhœa: various results.

"*Cholera epidemics* appear to have been rendered practically harmless in the towns examined" (p. 47). As instances of this we may cite the cases of Merthyr Tydfil, where a death-rate of 267 in 10,000 during the epidemic of 1848-49 was reduced in 1866 to 20 by improvements in the sanitary condition of the town, consisting of "imperfect but extensive nuisance

Cholera rendered harmless.

removal and public cleansing . . . by the regulation of common lodging-houses, and, since 1859, by a spontaneous reduction of crowding; since 1861 by the introduction of ample good water, and by the services of an officer of health" (p. 83). Alnwick, with a mortality of 205 in the epidemic of 1849, did not suffer at all in 1854 or 1866. Salisbury, from a mortality of 180, descended to one of 14½, while in 1866 it was untouched. There is *no exception* to this reduction. The case of Ely, of which it is said that "cholera, which had caused scattered deaths only before 1853, produced in that year and 1854 a small epidemic mortality; in 1866 two deaths only from cholera were registered" (p. 166), not being at all an exception, for the small epidemic in 1853-54 which occurred there was just at the very commencement of the sanitary works, and before the houses were connected with the new sewers.

Several instances.

No real exception.

But perhaps the most important result of these researches of Dr. Buchanan is the demonstration of one, at any rate, of the conditions most favourable to the prevalence of *phthisis;* a condition, too, which can in most cases be very easily removed. We were prepared to find that the mortality from cholera and from typhoid fever, and also that the general death-rate, would be diminished by these sanitary improvements; but, as Mr. Simon says in his Report, we were "not in any degree prepared" for "the novel and most important conclusion . . . that *the drying of soil which has in most cases accompanied the laying of main sewers in the improved towns has led to the diminution, more or less considerable, of phthisis*" (p. 16). It appears that in such towns as Salisbury, Ely, Rugby, Banbury, and so forth, where, as we have

Reduction in death-rate of phthisis.

Due to drying of subsoil by main drainage.

already seen, the drying of the subsoil has been considerable, the deaths from consumption have been reduced by a third or a half of their number. In Leicester, during the time the sewerage works were in progress, and for a short time after, when there was a great reduction in the subsoil water, the death-rate of phthisis "had subsided by 41 per cent of its previous amount at all ages, and by 32 per cent in the death-rate of females at the middle age of life. . . . Since the completion of the works, there is reason to believe that water has risen again in the subsoil, while the phthisis death-rate has somewhat risen also, but still remains much below its original amount" (p. 49). In the towns, on the other hand, where the drying of the subsoil has been inconsiderable, or has not taken place at all, "phthisis has been stationary, or has even increased." In some cases, as at Penzance and Brynmawr, this is due to the fact that the soil already contained little water, and so happened not to require draining; but such cases plainly form no exception to the rule. This drying of the subsoil has, we have already seen, only been effected in towns which have large sewers or deep storm culverts in addition to the pipe system, that is to say, "which have had special arrangements made for drying their subsoil, as Salisbury;" and that on the other hand, where pipe-sewers have been constructed with only superficial culverts for the storm water, or even without these, no drying has taken place. It is precisely in these towns—as Stafford, Morpeth, Ashby, Alnwick, and so forth, which have not had a special arrangement for drying the subsoil, while provided with impervious pipe-sewers—that the death-rate from consumption has not improved, or has even

Fluctuations in subsoil water and in phthisis death-rate.

Decrease only where subsoil specially dried.

Where *only* impervious pipe-sewers no decrease in phthisis;

increased. It must also be especially noticed that many of these last-named towns "have achieved the greatest possible progress in the removal of their filth." At Worthing and Rugby, where the pipe system is carried out, although no special arrangements were made for carrying off the subsoil water, it would appear that a great deal of it gets away—in the cas of Rugby by means of the old sewers which are still left, and, in the case of Worthing, along the sides of the pipe-sewers; and this would account for the considerable reduction in the mortality, under this head, of these towns. Carlisle and Chelmsford, on the other hand, have not received any benefit from the reduction of the amount of their subsoil water, because local conditions have nullified this effect. The environs of Chelmsford still get flooded through the action of a mill-dam, and one part of Carlisle is "so low that the subsoil is water-logged at all times, and, in flood, is practically under water" (p. 107). *Lung diseases* (other than consumption) would appear to have undergone no regular reduction in amount in the several towns. In some cases their mortality has increased, especially among old people, "who, it may well be believed, having had their lives prolonged by the subsidence of other causes of death, died afterwards from the lung disorders incident to old age" (p. 50). We cannot refrain from quoting the last sentence of Dr. Buchanan's Summary Report, which expresses the opinion of all who have seen anything of the results of sanitary improvements. "The progress made by the inhabitants of most of the twenty-five towns, in decency, cleanliness, self-respect, and morality, was at the least as striking as the improvement in their health, measured by the mortality returns." These researches show, in

except where accidental draining of subsoil.

No benefit where subsoil gets water-logged.

Other lung diseases often greater mortality: reasons.

Improvements in other particulars.

the most conclusive manner, that the removal of filth from a town, at once and in the most expeditious manner, is the way to decrease general death-rate, and the death-rates especially of cholera and typhoid fever, and they show also that the introduction of the water-closet system has effected most wonderful changes in these respects; thus proving to demonstration that the prevalence of the diseases above mentioned, which we have before shown to have been co-existent with accumulations of filth, was not merely co-existent with them, but due to them, or at any rate fostered by them; and they have shown that besides this, where-ever the sewers have been also subsoil drains, or where special arrangements have been made for drying the subsoil, the death-rate of phthisis has wonderfully diminished. We must therefore conclude that—since most authorities, Parent Duchatelet included, agree that the channels for the removal of excretal refuse should be impervious, and should, where practicable, be merely glazed stoneware pipes—it is absolutely necessary that at the same time there should be a special system of *deep* rain-water culverts to ensure the drying of the surface and of the subsoil.

Cholera and typhoid fever can be prevented.

Even phthisis is controllable.

Necessity of "separate" system.

When sewers do not properly perform their duty in removing expeditiously the refuse matter, but from bad construction or from want of flushing are allowed to become partially filled with foul matters which putrefy and give off noxious gases, and when, further, from want of sufficient ventilation of the sewers, these gases are allowed to escape into the air of the houses, all the results of want of removal of excrement may be expected.

Results of bad construction;

Thus, with the system of trusting to the rainfall to flush the sewers, it is found that after heavy storms the sewage, so far from being weaker, is, especially when it comes through badly constructed sewers, very many times stronger than it is ordinarily, and this is simply because it has stirred up and washed away the deposit of filth which has been accumulating.

of flushing only by rainfall.

Dr. Acland has shown us, in his account of the cholera at Oxford, that the virulent epidemics of it are preceded by droughts, remarkable droughts, making the total rainfall of cholera years sometimes as much as 10 inches less than the annual average, and we cannot fail to see the connection of this fact with the greater accumulation of filth that takes place in the drain-sewers under such circumstances.

Composition of sewer air.

The composition of sewer air is subject to wide variations. In badly constructed and ill-ventilated brick sewers, the amount of gaseous impurity is very great. Thus Parent Duchatelet found that a sample of air taken from a choked sewer in Paris contained only 13·79 per cent of oxygen, and as much as 2·99 per cent of sulphuretted hydrogen (*Hygiene Publique*, p. 390), while Dr. Russell's analyses of air collected from the sewers of Paddington, previously mentioned (see p. 211) gave results indicating a fair standard of purity.

Organic matter in sewer air.

In the fouler samples of sewer air, the proportion of organic matter is very large, and it is certain that this is not merely in the condition of organic vapour, but consists partly of foul organic matters in suspension, which are probably given off from the sewage to a considerable extent during decomposition, by the bursting of bubbles of gas (see Dr. Frankland's paper on "The transport of solid and liquid particles in sewer gases," in the Proceedings of the Royal Society, April 1877).

Modern research has shown that the specific poisons of some infectious diseases are particulate organisms, capable of living and multiplying outside the body, provided they be received, after evacuation from the body, in a suitable soil. Town sewage is probably a suitable soil or cultivating medium for some of these organisms, containing, as it does, animal and vegetable organic matter, phosphates and ammonia. The warmth of the sewage and the darkness of the sewer also favour the growth of organisms.

Specific poisons of infectious diseases.

Town sewage, a suitable soil.

That sewer air may become specifically infected has been shown in the case of enteric fever by the history of numerous epidemics, where the disease was spread by the passage of sewer air from unventilated sewers into houses (see pp. 219, 252). Thus an outbreak at Melton Mowbray was traced by Dr. Blaxall (Appendix to *Report Med. Off. Loc. Govt. Bd.*, 1881) to the occurrence of floods which backed up the sewage, specifically infected by typhoid evacuations, in the flat sewers; the compressed air in the sewers, unable to escape by the few ventilating openings there were, owing to these being blocked with clogged charcoal trays, entered the houses of the town through untrapped drain inlets and water-closets whose traps were dry from want of a proper water supply.

Sewer air may become specifically infected.

That the specific poison of cholera may also be conveyed in sewer air appears to be most probable from the investigation made by the late Professor Parkes on the introduction of cholera into Southampton in 1866, the report of which is published in the *Ninth Report M. O. P. C.* In this case the outbreak in the town was in all probability due to the passing of pumped sewage, infected with cholera evacuations, in a frothy and agitated condition along an open conduit.

Specific poison of cholera may be conveyed in sewer air.

The first cases arose in the "clean and airy" houses, which bordered this open conduit, and in which the smell from the pumped sewage was greatly complained of. As soon as the conduit was covered over, the epidemic abated.

Cholera communicated by sewer air.

The outbreak of cholera in the City of London Union Workhouse, in July 1866, the causes of which were investigated by Mr. Radcliffe (*Ninth Report of Medical Officer of the Privy Council*), was shown to have taken place, in all probability, from a sudden efflux "of sewer air from a drain containing choleraic evacuations," which efflux was favoured, if not caused, by rapid and considerable changes in temperature and barometric pressure. (*Loc. cit.* p. 316.)

Drinking water contaminated from bad water-closet pipe.

At Theydon Bois, in Essex, an outbreak was caused in 1865, in the following way:—A man and his wife came home from Southampton, where cholera had appeared eight days before.

Both used a water-closet on the first floor, between the soil-pipe of which and the well supplying the house with drinking water there was (as subsequently discovered) free communication. The water tainted with the diarrhœal discharges was used by the family and the man and boy mentioned, for five full days, during and subsequent to which several of the members were attacked with malignant cholera. (*Ninth Report M. O. P. C.*, p. 304.)

Fatal results.

Three persons not using the water, but who had been in communication with the sick, were also attacked. "Of the twelve cases, nine ended fatally, including the head of the family and his wife."

Many similar cases might be given, both with regard to cholera and typhoid fever, but enough has been said to convince us of the truth of Dr. Duncan's remark, that "the prevalence of fever and the rate of mortality proceed inversely as the efficiency of sewerage." (*First Report H. of T. C.*, 1844, vol. i. p. 152.)

The question as to whether sewage which has become specifically infected with cholera or typhoid dejections is most dangerous when fresh, or when undergoing fermentation and putrefaction, is still unsettled. The history of the Croydon outbreak in 1875 (see p. 221) tends to show that the air of unventilated pipe sewers, which had no offensive smell, the sewage being carried away fresh and undecomposed, was capable of producing a sudden and severe outbreak of enteric fever. And Dr. Buchanan was of opinion that "the material of contagion is perhaps less likely to be active in excrement that has passed into fœtid decomposition." On the other hand, the air over putrid sewage contains a far larger proportion of suspended organic matter than the air over fresh sewage, and in this suspended matter may be contained the particulate organisms of disease. The history too of numerous outbreaks of enteric fever, in which sewer air conveyed the contagion, show that the sewer air came from foul unventilated sewers, and had a very noticeable and offensive smell.

Fresh sewage may be dangerous.

Sewage is not necessarily harmless when putrid.

In brick sewers, however carefully constructed, owing to the variations in the height of the flow of the sewage, a deposit tends to form on the walls; this deposit being alternately wet and dry, soon putrefies and parts with the putrefactive ferments to the sewage in contact with it. Drs. Parkes and Sanderson * examined the deposit of sewer slime in the sewers of Liverpool, and found it to contain ammonia and nitrates and large quantities of fungi and bacteria; thus showing that it would be a favourable cultivating medium for those disease germs which are capable of existing outside the animal body. In pipe sewers the

Deposit in brick sewers.

* Report on the Sanitary State of Liverpool, 1871.

Less tendency to deposit in pipe sewers.

slime deposit will not take place to such an extent, owing to the smooth internal surfaces of the pipes, and the greater frequency with which they are washed, as pipe sewers of small diameter are often running full or nearly full.

Water system a great benefit.

The general introduction of the water-carriage system has therefore been a great sanitary benefit, and wherever it has worked badly it is owing to most flagrant mismanagement or want of reasonable precaution.

The great charge brought against it is that of carefully connecting every part of the town, the streets, and even the interior of houses, with a series of filthy underground channels in which foul gases accumulate, and rising to the highest parts escape and pollute the atmosphere. That proper flushing will easily prevent the formation of any great quantity of these gases, we have instances enough to show, and by disconnecting the house drain from the street sewer, the entrance of sewer air into the house will be entirely prevented. That gases formed in the sewers may be removed inoffensively by ventilating shafts when they do accumulate, is also certain; but that by careful avoidance of flushing sewers of low gradient which require it, and thereby favouring the deposition of filth, and by neglecting to provide any ventilating shafts, sewer gases may be manufactured in large quantities, and driven effectually into the streets and even into the interior of houses whose drains are not disconnected from the street sewer, is an undoubted fact and requires no demonstration. Nay, more than this, apparatus excellent in idea up to a certain point may be so cunningly devised as to act well for a time and under ordinary circumstances, and yet, just when

Flushing and ventilation of sewers necessary.

its services are most wanted, to fail in the most abject manner and with the most disastrous consequences, simply because it has been expected to perform two perfectly incompatible functions.

At Croydon the soil-pipes from the water-closets were ventilated by a pipe which passed upwards from them (below the soil-pan and siphon) towards the roof—an excellent plan; but this pipe, instead of rising above the roof and ending in the air, was made *to end near the upper part of the rain-water cistern, and to act as its waste-pipe!* And what was the result? Dr. Alfred Carpenter describes it thus (see *Ninth Report of Medical Officer of Privy Council*, p. 104):—

Ventilating-pipe connected with rain-water cistern.

On the night of 17th October I was aroused by a loud noise proceeding from the closet; it continued at intervals throughout the next day. Unable at first to account for it, I eventually found that it was caused by the ventilating-pipe doing duty as waste-pipe to the overflowing cistern (during a very heavy rainfall). There was no room for exit of foul air from the sewer, which, therefore, was forced through the trap of the water-closet, with, at times, the force of steam through the safety-valve of a steam-engine. The nuisance continued for nearly three days, before the weather would allow the plumber to rectify a mistake which had been committed in the previous summer, the mistake of making the ventilating-pipe do duty for a waste-pipe. The escaped air did not smell offensively, a faint odour alone being recognised; it was therefore thoughtlessly tolerated: the excessive rainfall also prevented much ventilation of the house by open windows. Two or three days afterwards, one of the occupants of a room, the farthest in the house from the closet, fell ill with symptoms of typhoid fever, and in a few days the other person sleeping in that room also showed signs of the disease; no other person in the house suffered from it. Into the room occupied by these two persons the foul air from the closet, as proved by experiment, naturally ascended. Simultaneously with the origin of these cases appeared many others in various parts of the town, and in every case in my own practice in which enteric or typhoid fever occurred, I distinctly traced local causes for the disease in some defective housework. It generally happened that the smell was not enough to lead to the discovery of the defect, a faint odour alone being perceived.

Sewer air forced into houses.

Not offensive.

Typhoid fever appeared.

Always local defects.

It would be difficult to imagine a more ingenious method for delivering sewer gases at high pressure into houses than the one above described, and it succeeded only too well.

Mistakes.

But such mistakes occurring simply through want of forethought do not in any way show the incapacity of the water system of removal. That a certain builder chose to ignore the fact that gases cannot freely rise up a pipe while water is rushing down it, and that ventilators are most wanted to be in an efficient state when the sewers are suddenly flooded with water and the gases consequently under considerable pressure; that he considered himself justified in saving a few feet of piping by the proceeding that he adopted; and that the results were most lamentable, are simply facts which show the necessity of educated sanitary inspection. They have nothing whatever to do with the general question of refuse removal. Who would think of condemning the introduction of coal gas into houses because there are occasional instances of gas escaping from faulty stopcocks?

Not the fault of the system.

Coal gas really less dangerous than oil lamps.

Coal gas is no doubt a very dangerous thing if proper precautions are not taken to ensure its being kept in its own place; but it is not merely its convenience and cleanliness that have caused it to be almost universally adopted in preference to oil lamps; it is a fact that the occurrence of accidents with it can be effectually prevented, and it is for this reason that it is always used in preference to oil lamps, where any danger is apprehended. It is not merely the great convenience of water-closets that has ensured their general adoption, but the thorough-going manner in which they remove excretal matters from the premises at once.

Of the sanitary advantages of water-closets, and especially of the *trough closet*, over middens and cesspools, Liverpool affords us a most instructive instance. Dr. Trench writes as follows :—

In 1868 there raged a wide-spread epidemic of typhoid fever in the town, and in the rural districts in the vicinity of the town. . . . While in the families of the rich in their costly suburban dwellings there was raging a fever, clearly and unmistakably due to the pestiferous emanations from ill-drained cesspools or other collections of filth or decomposing organic matter, the districts in the borough of Liverpool known as the fever districts, and wherein no midden-steads or cesspools were allowed by the Council to remain unaltered, continued during the whole period of the epidemic remarkably healthy and free from fever. (*First Report R. P. C.*, 1868, vol. ii. p. 307.)

Typhoid where cesspools in rich parts.

Not where trough water-closets in poor neighbourhoods.

The experience at Birkenhead of the working of the *tumbler closet* is equally satisfactory where it has been properly fitted up.

"Tumbler" closet works well.

Mr. Thorburn, the surveyor, finds that as compared with the ordinary privy "the tumbler closet for sanitary purposes is undoubtedly the better of the two."

All other systems than that of removal by water go upon the principle that it is not dangerous to leave excretal matters, either in a crude state (pail closets) or mixed with some absorbing or deodorising material (various other forms of closet), for a certain time in or about houses. The fundamental principle being *obviously* a wrong one, it is not to be wondered at that such systems continually fail. When pails get over-filled, or slops are thrown down earth closets, the results may be better imagined than described; and it has practically been found necessary to construct earth and ash closets so that the fluids may run away into the sewers, while the solids are carefully kept upon the premises, being partially rendered inoffensive by admixture with ashes or earth, or dried by a rotatory disc under the seat, or by some other contrivance.

Conservancy systems, wrong principle.

Harmlessness of earth compost not shown.

There is one evident objection to all these dry plans, viz. that the excreta are retained about our houses for some time. No doubt when mixed with earth they are inodorous, and it is presumed harmless; but of this no evidence has been given. What would be the result of cholera or typhoid discharges received in earth and allowed to remain in the house? (Dr. Parkes, *Hygiene*, 3d ed. p. 354.)

Correct principle.

The water-carriage system, on the contrary, sends all the refuse matters at once to a distance in the cheapest manner possible, by the mere action of gravity; this is plainly a safe principle to go upon, and that it acts in practice may be seen by any one who chooses to examine the fæcal matters in the sewage at the outfall of a town supplied with impervious pipe sewers properly flushed; he will find them fresh and undecomposed.

The Committee of the British Association on the Treatment and Utilisation of Sewage arrived at the following conclusions (Report 1873, p. 449):—

The water-carriage system based upon a sound principle.

The water-carriage system . . . is based upon a sound principle, that of removing all the refuse matters at once, and in the cheapest possible manner, by gravitation, and ought to be resorted to in all but the most exceptional cases. The opinion of the Committee, that all sewers should be made of impervious materials, and that separate drains to dry the subsoil should be constructed where necessary, has already been most emphatically expressed. The freest possible ventilation of sewers, house drains, and soil-pipes, in order to prevent accumulations of foul air, is also essential.

The above considerations induce us to endorse the general opinion in this and other countries, that the *cabinet anglais* is in all essential particulars far superior to every other form, not even excepting the *cabinet inodore*.

Figures are stubborn things to deal with, and the sanitary benefits already obtained by this system are so astonishing, that we have a right to demand from those who would supplant it proof of much better results realised by some other method, and not mere doubtful probabilities.

CHAPTER VIII

VALUE OF SEWAGE—INJURY TO RIVERS—POLLUTION OF DRINKING WATER—DISCHARGE OF SEWAGE INTO TIDAL WATERS

THE composition of sewage varies so much, not only in different towns with the amount of water supply, but in the same town from day to day, and even from hour to hour, that in estimating the composition of any given sewage it is not only necessary to take samples of it at least once every hour for twenty-four hours, and to mix them in order to procure an average sample, but these various samples must also be mixed in direct proportion to the amount flowing as indicated by the gauging at each time of collection. It is plain that if a gallon of sewage, taken at a time when the liquid is running very low in the sewer, be mixed with another gallon taken at a time when the sewer is much fuller, the mixture does not represent the average composition of the sewage at the two times. A gallon of the one should not have been mixed with the same quantity of the other, but with a quantity proportional to the amount running through the sewer at the time. These considerations not having been borne in mind in the collection of samples for analysis, the results hitherto obtained must be received with a certain amount of caution; but still an average taken of accurate analyses made to ascertain the composition

Average samples, how taken.

of the sewage of a great number of towns may be fairly taken as representing to all intents and purposes the composition of sewage. Such an average is given in the First Report of the Rivers Pollution Commissioners (1868), where it is shown (vol. i. p. 29) that in water-closet towns 100,000 parts of sewage contain 72·2 of total solid matters in solution, in which there are 4·696 parts of organic carbon, 2·205 of organic nitrogen, 6·703 of ammonia, an almost inappreciable quantity of nitrogen as nitrates and nitrites, the total of combined nitrogen being 7·728 parts, and the chlorine 10·66. Besides these matters in solution, the 100,000 parts contain 44·69 of suspended matters, of which 24·18 are mineral and 20·51 organic. But it must be carefully borne in mind that this is an average, and that there are extremes. To take the total combined nitrogen as an example, it was found to vary, in the London sewage alone, from about 3 parts to more than 11 in the 100,000, while in all the samples examined its variation was from 2·371—the Norwood sewage, on 25th February 1869 (which sewage, however, on 12th March contained 9·681 parts of combined nitrogen)—to 24·325 parts, the amount contained in the sewage of Woking prison on 9th July 1869. These variations are not to be wondered at when not only the differences in the amount of water supply are taken into account, but the fact that in the drain-sewers of most towns the subsoil water, the ordinary rain water, and even the storm water, pass along with the sewage and dilute it. Sewage then, under these conditions, which is very strong at one time, may become exceedingly diluted at another, and this is the great difficulty that has to be encountered in any attempt at the utilisation of town sewage.

Average composition.

Great variations,

from varying amounts of rainfall, water supply, etc.

Sewage is a very complex liquid ; a large proportion of its most offensive matters is of course human excrement, discharged from water-closets and privies, and also urine thrown down gully-holes ; but, mixed with this, there is the water from kitchens, containing vegetable, animal, and other refuse, and that from washhouses, containing soap and the animal matters from soiled linen. There is also the drainage from stables and cow-houses, and that from slaughter-houses, containing animal and vegetable offal. In cases where privies and cesspools are used instead of water-closets, or these are not connected with the sewers, there is still a large proportion of human refuse in the form of chamber slops and urine. In fact, sewage cannot be looked upon as composed solely of human excrement diluted with water, but as water polluted with a vast variety of matters, some held in suspension, some in solution. (*First Report of Rivers Pollution Commissioners*, 1868, vol. i. p. 13.)

Contents of sewage.

The quantity of these matters and the value of their constituents as manure can be very easily determined, and we have already seen that the estimated value of the annual voidings of an average individual of the mixed population of all ages and both sexes, is 8s. 4d. if the amount of ammonia be considered to be 12½ lbs. ; but if we consider with Messrs. Lawes and Gilbert that this amount has been somewhat exaggerated, and that 10 lbs. of ammonia is a fair estimate of the average individual amount, the sum of 6s. 8d. would then represent the total annual value of average human excreta. This is the lowest value that has been assigned to it. If then the number of individuals in a town were known, and the amount of waste water turned into the sewers tolerably constant, as it would be were the rain water excluded, the value per ton of the sewage varying inversely as the dilution, this value at any given place might be simply calculated from the number of inhabitants, and could be easily corrected by the results afforded by the analysis of an average sample collected in the manner above described. But the actual circumstances of the case and the extreme variety in the degrees of dilution of the liquid

Value of excreta.

Calculation from number of inhabitants.

in drain-sewers must necessarily give very different degrees of value to the same sewage at different times, not to speak of the diurnal variations necessarily caused in all cases by the fact that the greatest part of the refuse matters is discharged into the sewers in the early part of the day, and comparatively little at night; so that the night sewage is in many towns little else than water.

Variability of dilution.

The chief valuable ingredients of sewage are, first, the different forms of combined nitrogen, and then, phosphoric acid and salts of potash. "The money value of these constituents *dissolved* in 100 tons of average sewage is about 15s., while the *suspended matters* contain only about 2s. worth of them." That is to say that 100 tons of average sewage are worth 17s., or about 2d. a ton. This value, given by the Rivers Pollution Commissioners (*First Report*, vol. i. p. 52), is very nearly that assigned by Messrs. Hofmann and Witt, in their Report upon the subject. They found that sewage collected on the 13th of May 1857, at various times, and mixed, contained 94·7 grains of solid matter in a gallon, of which 19 were in a state of suspension, and 75·7 in a state of solution; and on the 11th of June a mixture of samples contained 111 grains, of which 32·7 were in suspension and 78 in solution, and they found that six-sevenths of the valuable matters were in a state of solution, and only one-seventh in suspension. They considered that the average might be taken as 100 grains of solids per gallon (*i.e.* per 70,000 grains), and that therefore 70,000 tons of sewage contained 100 tons of solid matter. Of total nitrogen they estimated 6·7 grains in a gallon, of phosphoric acid 1·8 grains, of potash 1 grain. Now, 100 tons of solid constituents contain

Value, 2d. a ton.

Composition.

Quantity and value of constituents.

8 tons of ammonia, and a ton of ammonia in the form of guano is taken as being worth £56 (it is now worth £65 : 6 : 8): the total value of the ammonia is thus found to be about £447; and employing the same process for the rest—that is, taking the commercial value of each of the constituents—the 100 tons of solid matters are found to be worth £601 : 3 : 6, or £6 : 0 : 3 a ton: of these the dissolved matters are worth £5 : 5s., and the suspended matters 15s. 3d. Since one ton of solid matter is contained in 700 of sewage, it follows that 100 tons of sewage are worth 17s. 7d., or a little more than 2d. a ton. Messrs. Lawes and Gilbert, in their paper before quoted, have given a table in which the value per ton of the sewage is estimated at various degrees of dilution, and it is there shown that if the dilution of the dry weather sewage of London be taken, as indicated by recent gaugings, at about "24 gallons per head per day, equal to a rate of 40 tons per head per annum," the estimated value per ton of it is nearly 2½d., if 12½ lbs. be taken as the amount of ammonia per head per annum, and 2d. if that amount be taken as 10 lbs. These values decrease with increasing dilution until, when this amounts to 200 tons per head per annum (or 122¾ gallons per head per day), "the probable frequent dilution in wet weather, inclusive of rainfall and subsoil water," the value is only a half-penny a ton in the one case and two-fifths of a penny in the other.

Dissolved matters far more valuable than suspended only.

Variation of value with dilution.

In the Third Report of the Sewage of Towns Commissioners (1865), it is considered that 60 tons per head per annum is the average amount of normal, or dry weather sewage in the metropolis.

It is further variously estimated that by subsoil water and rainfall, the bulk of the fluid will be increased by from two-thirds to an

Lowest estimate.

equal volume. Adopting the lower of these suppositions, which, if too low, will allow something for the occasional escape of storm water, we have the 100 pence worth of constituents distributed through 100 tons of fluid, giving to it a value of one penny per ton according to the estimated market value of its manurial constituents. (*Loc. cit.* p. 42.)

If we take now the estimate of Baron Liebig and Mr. Ellis, that 266,000,000 tons is the total annual amount of dilute London sewage, we find that at one penny a ton its value is £1,108,333 : 6 : 8. There can be little doubt that the average of 100 tons per head per annum is greater than the average dilution, so that this estimate is the lowest that can be formed. To take, on the other hand, the value of the excreta of each individual of the population as above given, it will appear that the sewage from 3,000,000 people ought to be worth just £1,000,000, if only 6s. 8d. be taken as the value of each person's excreta; but that the same quantity would be worth £1,250,000 if the higher value of 8s. 4d. be taken. The average sewage of the dilution above stated, namely, 100 tons per head per annum, is found to contain 3·91 grains of ammonia per gallon; that is to say, with about four grains of ammonia in the gallon, the sewage may be considered to be worth one penny per ton; or for each grain of ammonia per gallon the sewage is worth a farthing per ton. We may remark in passing, that very much higher values than this have been assigned to the sewage of the metropolis. Thus Messrs Hofmann and Witt considered that the total amount of the metropolitan sewage, not including rainfall, was about 95,000,000 gallons a day, or about 158,000,000 tons per annum (as 224 gallons weigh a ton), and calculated that it was worth £1,385,540 a year; and they considered that the theoretical value of the excreta of 2,600,000 people was £1,444,177 (*First*

Value of excreta.

Rough way of estimating the value of sewage.

Higher estimates.

Report of Select Committee on the Sewage of Towns, 1862: *Dr. Brady's*). This estimate, being deducted from the value of the excreta of a full-grown man, is too high for that of a mixed population.

The population of London at the present time, 1886, exceeding 4,000,000, if 6s. 8d. be taken as the value of each person's excreta, the total annual value will be $1\frac{1}{3}$ millions sterling; or if the average dilution be 100 tons per head per annum, at a penny per ton, the total annual value will be $1\frac{2}{3}$ millons sterling.

Value of the metro-politan excreta.

The above estimates are quite thrown into the shade by Baron Liebig's calculations. From experiments of which we do not know the nature, he seems to have come to the conclusion that the annual value of the metropolitan sewage is no less than £4,081,430 sterling. But throwing aside all these higher valuations as either extravagant or unnecessarily high for our purpose, we ask, with the writer of a paper containing practical suggestions for removing all the sewage from the dwellings in and about London, "Shall the sewage of the metropolis, calculated to be worth more than a million annually, *be worse than wasted?*" That sewage is wasted when turned into a watercourse cannot be denied by any one; that it is worse than wasted we shall now proceed to show.

Baron Liebig's valuation.

Sewage "worse than wasted."

INJURY TO RIVERS.

The effect of sending the sewage into rivers is injurious from many points of view. Let us first consider the rivers merely as watercourses, without any reference to the subsequent use of the water for drinking purposes. The Sewage of Towns Commissioners, in their First Report in 1858, make the following statement:—

Rivers turned into sewers.

> The discharge of a large body of sewage into a river or watercourse is frequently not only productive of nuisance and disease to the neighbourhood where it takes place, but its influence extends to distant populations. Many rivers, especially in the crowded districts of the North of England, pass through several towns in their course seawards, and, receiving from each its complement of sewage filth, are even now little better than sewers themselves, although comparatively few of those places have yet carried out any complete works of water supply and sewerage. (*Loc. cit.* p. 9.)

Still worse since new sewerage arrangements.

The suggestion implied at the end of this quotation makes us remark that the more perfectly water-closet and sewerage arrangements are carried out, with all the immense advantages from a sanitary point of view we have already shown them to afford to towns, they will only increase any detriment that may be done to the rivers so long as the sewage is allowed to pass into them. Of the Tame, it is stated that before reaching Birmingham it "receives the sewage of a number of towns containing a total population of no less than 270,000 persons. A small stream in itself, it may without exaggeration be said, during dry seasons, to contain, at Birmingham, as much sewage as water. That such a stream, traversing a densely populated town, and exposing to the air a large surface of putrid liquid, must be very injurious to health, no one can doubt."

Influence of emanations from river on health not determined.

The influence of the emanations from such rivers upon the health of the people living in towns upon their banks, has not, however, been distinctly traced, owing to the fact that the other causes of disease in these towns throw this one into the shade, and from "the difficulty of estimating apart the influence of the river upon health in the presence of morbific influences so much more powerful than itself."

From the Ninth Report of the Medical Officer of the Privy Council (p. 152), we find that at Salisbury, the branch of the Avon into which the sewage flows "has to be frequently cleaned out, or it would get choked by the sewage and rank weeds;" yet there is very little offence, probably from the very fresh state of the sewage, the sewers acting remarkably well.

At Stratford "the river is befouled by the sewage where it enters half a mile below the town, and there is considerable offence to eye and nose at the outfall. Evidently the sewer does not carry off night-soil before it has had time to decompose. The river used to be a beautifully clear stream." Offensive condition of rivers.

Dr. Acland's evidence before the Sewage (Metropolis) Committee, 1864 (Lord Robert Montagu's), showed the condition of the Isis at Oxford: "Masses of black sewage which have been deposited are thrown up to the surface, and, being light, float upon the surface and are carried down, and then in course of time either those masses become disintegrated and generally dispersed through the water, or they get redeposited." (*Loc. cit.* p. 148.)

With regard to the northern towns, the Rivers Pollution Commissioners (1868) in their First Report have brought forward a considerable amount of evidence. All the sewers pass into the rivers, and— In northern towns.

> The improvements in the sewerage works of Bury and of the towns above have had an injurious effect on the water of both rivers (the Irwell and Roch), making it more offensive. The people complain that the water is most offensive to the sight and smell; that it is unfit for use; that even when used for steam-engines it clogs up the boilers and is injurious to the machinery.

As a summary of the evils thus produced the Commissioners remark:—

The effect of this conversion of the rivers into common sewers is most injurious: all complain, even those who, while suffering from the inconvenience and annoyance which such a state of things entails, add to the nuisance by themselves following the general example; while they whose property happens to lie on the stream, even many miles below the towns, are sufferers in a variety of ways. Are they farmers? Their cattle cannot drink of the stream passing through their meadows. Are they dwelling on or near the bank of the river? They are driven from home by the stench which renders the place unbearable. Are they compelled by duty to remain on the spot? They are subject to perpetual annoyance, and, as alleged, in many instances to ill health. Have they property? Its value is often diminished; a house remains tenantless; land is unsaleable, except at a reduced price. (*First Report*, vol. i. p. 12.)

Injuries from pollution of rivers.

The First Report of the Royal Commissioners on the Metropolitan Sewage Discharge, 1884, gives numerous striking illustrations of the state of the tidal portion of the Thames, and the nuisance and inconvenience arising from its pollution with the great mass of metropolitan sewage. We may quote the following from their Report (p. 51):—

Pollution of the tidal portion of the Thames.

Eleven and a half millions of cubic feet of concentrated sewage enter the river during three hours every tide. The stream of sewage flows out at Crossness under the surface of the water in the river. At Barking it discharges at a higher level, and part of the time not under water; but in both cases it immediately becomes appreciable, and continues (as is usual where one stream joins another) unmixed for a considerable distance. It is allowed on all hands that this sewage stream, so long as it retains its separate character, is very offensive in its immediate neighbourhood. After a time the sewage stream begins to mix with the water of the river, and the mixture becomes less offensive. The solid matter, to which more than to the fluid they (the witnesses) attribute the origin, proximately or remotely, of the offensive smells, decomposes, the noxious gases which result are dissolved in the water, and when the water is stirred up they escape into the air. This agitation is effected by the passage of steamers, and as the traffic is very great the effect is kept up for a considerable distance from the outfalls, both up and down the river. Within this range the water is in such a foul state as not to be usable, even for such purposes as washing ships' decks, etc. After a further time and a more extended travel of the sewage discharge the mixture with the river water becomes more complete, and a change takes place on which great stress is laid by the Metropolitan Board of Works. They assert that by the dilution with the river water, and by the constant agitation due to the tidal oscilla-

Streams of sewage.

Very offensive.

Solid matter decomposes.

Water not usable.

tion and other motions, a process of natural purification by oxidation sets in, which in time deprives the discharged fluid of its offensive properties, and causes it to become more like the natural water in the river. . . . The limits of distance above and below the outfalls where this purification becomes effective in preventing nuisance, are very indeterminate, varying much at different periods according to the supply of water to the river and the temperature. We may, however, state that there has been no evidence to lead us to believe that any substantial nuisance attributable to the metropolitan sewage is complained of above Greenwich or below Greenhithe.*

Purification by oxidation.

No nuisance above Greenwich or below Greenhithe.

In the same Report (p. 63) the magnitude of the causes in action which produce the pollution of the river are considered. It is stated that there is discharged into the river every day as much undiluted sewage as would fill a length of 750 feet of this part of it at low water. In estimating the quantity of foul matter which this discharge must contain, the amount of fæces alone, in their natural state, passing from 3,800,000 people, has been stated at something like 400 tons a day; and if the urine and foul matter from other sources and of other kinds be considered, the total quantity must be very much larger. The Commissioners then say:—

Amount of sewage discharged.

Amount of foul matter.

The idea that these large quantities are unimportant in comparison with the magnitude of the river into which they are discharged is, as we have already shown, incorrect. It would be difficult to suppose that such enormous amounts of polluting material could be destroyed by purifying action in so short a time as would be necessary to free the river from nuisance in the neighbourhood of their discharge. It is surprising that the nuisance is so far mitigated as we find it to be.

Nuisance must arise.

The Commissioners, however, found no reason to believe that "the offensive exhalations are perceptible in such a degree as to cause nuisance to any great distance inland from the banks of the river." They considered that whatever nuisance there is, affects only persons who are either on the river or on its immediate margin.

No nuisance inland.

* The distance from Greenwich to Greenhithe is about 16 miles.

As regards injury to health from the sewage emanations from the river, the Commissioners remark:—"We cannot see sufficient evidence to show that hitherto the sewage discharge has produced any serious injury to health, either among those who live in the vicinity of the river, or those who live partially or wholly on the water in the neighbourhood of the outfalls." But the evidence given before the Commissioners shows that "the sewage discharge does occasionally produce inconvenience, temporary indisposition, and a low state of vitality; the cause of which ought not to remain if reasonable means can be found for its removal. This result is, however, limited to those who are either actually upon the river or on its margin; for we have strong and trustworthy evidence that the smell is not perceived a short distance from the river. The constant presence of a large mass of water containing a vast quantity of crude sewage constitutes a danger to public health which demands attention, more especially as the evil must increase with the growth of population. (*First Report, Royal Commission on Metropolitan Sewage Discharge,* 1884, p. 50.)

No serious injury to health.

Causes a low state of vitality.

Danger to public health.

On the 9th of July in the summer of 1884 five of the Commissioners went on the river to examine its state, the weather being warm and the quantity of land water, owing to long-continued drought, being much below the ordinary summer average. The Commissioners found a condition of things which they denounced as "*a disgrace to the Metropolis and to civilisation.*" At Greenwich Pier "the water was very black and the smell excessively strong," whilst at Woolwich "the river for its whole width was black, putrid sewage, looking as if unmixed and unalloyed.

"A disgrace to the Metropolis and to civilisation."

The stench was intolerable." "Some of the sewage must have reached within a short distance of London Bridge." Three out of the five Commissioners who went upon the river, together with the clerk who attended them, were attacked during the night after their visit with severe diarrhœa, which they could not attribute to any cause except the nauseating odour from the river. The crew of the steamer also complained strongly of the general effect upon them. (*Second Report, Royal Commission on Metropolitan Sewage Discharge*, p. 9.)

"Stench intolerable."

Caused severe diarrhœa.

Another evil, besides the general one which has been noticed above, is the destruction of fish in the rivers, thus referred to by the Sewage of Towns Commissioners (*First Report*, p. 11):—"The salmon fisheries of Scotland and Ireland not only represent a property of large annual value, but they form the occupations and livelihood of a very considerable population. Apprehensions are already entertained of serious injury by the daily increasing quantity of sewage thrown into the rivers, and efforts have been made with a view of arresting the evil." It is then stated that in the case of Leicester the fish which had been driven from the river returned to it as soon as a process "for neutralising the offensive and noxious properties of the sewage discharged into the river" had been adopted (the "A B C" process).

Destruction of fish.

Much evidence was given before the Royal Commissioners on the Metropolitan Sewage Discharge (*First Report*, p. 64) as to injury to fish in the river Thames below London.

Injury to fish in the Thames.

The testimony of all the witnesses on behalf of the complainants, in regard to this, is the same, namely, to the effect that whereas formerly fish were caught in the neighbourhood of Woolwich, Erith, and

Fish have been driven away.

so on, since the main outfalls have been opened the fish have been driven down to a much lower point, *i.e.* to Gravesend or below. It is now at times impossible even to bring them alive through the water of the river above Gravesend. . . . These facts were admitted by the respondents, but the effect was attributed by them, not to the noxious qualities of the sewage but to the absence of oxygen, which had been abstracted from the water in effecting the purification of the sewage.

Disappearance due to the sewage discharge.

The Commissioners then remark:—"Without deciding whether this is the true or the only explanation, the facts remain that the fish have disappeared from this part of the river, and that their disappearance is due, either directly or indirectly, to the sewage discharge."

Silting up of rivers.

A still more serious question is that of the silting up of the rivers by the deposit of the solid material of the sewage. In the Second Report of the Sewage of Towns Commissioners (1861), p. 8, we find that—

Navigation impeded.

With regard to the Mersey, there is said to be evidence already that the bed is raised, that the deposit has *permanently* much increased. . . . At Bath the discharge of sewage into the River Avon is said to have so increased of late years as to impede the navigation. . . . The drainage of Glasgow is stated to produce deposits in the harbour of the Clyde at the rate of 100,000 cubic yards yearly, and to entail an expenditure of £8000 per annum for its removal. . . . The streams flowing through Birmingham are said to have permanently silted up their beds some four feet high, and serious damage to land and property by flooding is the result.

Rubbish and sewage.

In the northern towns examined by the Rivers Pollution Commissioners, the amount of ashes and rubbish of various sorts thrown into the rivers no doubt helps to silt them up so fast, but in some of the instances above given this is effected entirely or almost so by the deposit from the sewage itself. In 1867 the secretary of the Thames Conservancy Board drew the attention of the Metropolitan Board of Works to the fact of "the formation of extensive shoals in the River Thames, outside the Main Drainage outfalls near Barking Creek and Crossness," sending also copies of

Shoals in River Thames.

plans and sections made by the engineer of the Conservators of the River Thames, from surveys made in 1861 and 1867, "which show the extent to which the deposit of material from the sewer outlets has taken place on the bed of the river. From these it appeared that between 1861 and 1867 the deposit of mud had been very extensive. Near the southern outfall the deposit "occurred to the greatest extent on the lower side, where a depth of fully seven feet has been discovered; in front of and above these works there is also a considerable increase." Near the northern outfall, on the contrary, the greatest accumulation took place on the upper side as far as 2000 feet above the point of delivery, in several places a depth of 7 feet of mud having formed. That this mud, although extending so far above the outfall of the sewer, was really deposited from the sewage and carried up by the tide, is evident from its composition. It was found by Dr. Letheby to contain not less than 15½ per cent of organic matter, and besides that "an unusually large amount of carbonate of lime in a crystalline condition," which may be taken as evidence "that the alkaline constituents of the sewage are decomposing and precipitating the calcareous constituents of the water and thus adding to the bulk of the deposit." "The result of the survey shows that near the northern outfall a space of more than forty acres, and near the southern outfall of about 120 acres of the bed of the river has been covered by a deposit varying in depth down to seven feet" (Mr. Stephen Leach). Mr. (now Sir Joseph) Bazalgette considered "that alterations have taken place in the bed of the river, but that there has been only a very small increase in the total quantity of deposit." He found

Southern outfall.

Northern outfall.

Deposit carried up by tide.

Area of deposit.

that between the years 1864 and 1867, that is since the outfalls began to discharge, the deposit had increased in some places to the extent of 983,000 cubic yards, and in others had decreased about 923,000 cubic yards, leaving a total increase of about 60,000 cubic yards. But some plans which were made in the year 1870 show that the low-water line in some places above the northern outfall had receded to the extent of nearly 200 feet, and that it had receded considerably both for some distance above and for some distance below that outfall; and, moreover, they also show that at the point above this outfall, where the deposit of mud was shown to be 7 feet in 1867, it was in 1870 from 8 to 10 feet in thickness, and that near the southern outfall it was in many places from 5 to 10 feet thick. That is to say, that it had considerably increased since 1867, in many places at any rate. In fact, considerable banks of mud were forming on each side of the river, and promised to impede seriously the navigation. That this deposit of mud occurs to such an extent above the northern outfall would be matter of some surprise had we not before us the result of some important experiments by Mr. Frank Foster, subsequently repeated by Captain Burstal, R.N., and Mr. (now Sir Joseph) Bazalgette, C.E. With regard to this point it had been already remarked that the 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." A float was therefore put into the centre of the river opposite Barking Creek two hours after high water: "at low water the float reached $11\frac{3}{4}$ miles below that point, and returned with the next flood tide to one mile

Deposit removed in some places.

Narrowing of bed of stream since 1867.

Deposit above outfall.

Experiments with floats,

above it, having gone $12\frac{3}{4}$ miles that flood, it being then a period of spring-tides." Being left on the river, it was found that, between 13th July and 24th July 1851, it being then a period of neap-tides, the float at high water was 13 miles below Barking Creek; that is to say, that it had gone down the river 14 miles during the falling from spring to neap tides. The next spring-tides carried it up to "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."

from spring to neap tides,

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 $6\frac{1}{2}$ miles above Barking Creek at high water. The float then again worked down the river till the 20th of August, $9\frac{1}{2}$ 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 14 days (in the last case it was only 5 miles in 14 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 one mile a day at each high water as the springs strengthen, and down the river two miles a day as they fall off. (*Report of Mr. Robert Stephenson and Sir William Cubitt, Dec.* 1854 ; Bazalgette on the *Main Drainage of London.*)

from neap to spring tides.

Rate of motion up and down river.

These experiments prove conclusively that matters suspended in water may, although thrown into it after high tide, be brought back by the next tide considerably above the place of outfall, and there kept for some time; so that it is easy to understand that such matters as do not get deposited when going down the stream may be brought back again and deposited higher up it.

Matters may get deposited above the outfall.

A large series of float experiments were carefully conducted for the Royal Commission on Metropolitan Sewage Discharge (1884). The chief points

Float experiments

shown by these experiments are given in their First Report (p. 45), they are as follows :—

Extent of tidal oscillation.

1. The extent of the tidal oscillation varied considerably; the variation being due, not only to the character of the tide, but also probably to the position any particular float happened to occupy in the river, some parts of which move faster than others.

Maximum range of oscillation.

2. The maximum range of oscillation recorded, at spring-tides, was about 18 miles, the minimum, at neap-tides, a little under 7 miles; the mean of the whole of the observations gave about 12½ miles.

3. A float which was started from the northern outfall at high water is said to have ascended with subsequent flowing tides to a distance of 7 or 8 miles *above* the outfall, or to Greenwich.

4. Another float which was started from the northern outfall three hours after high water, is said to have ascended, with subsequent flowing tides, to a distance of 20 miles above, or between Putney and Hammersmith bridges.

5. Another float which was started from the northern outfall at low water is said to have ascended with subsequent flowing tides to a distance of 21 or 22 miles above, or between Hammersmith and Chiswick.

Sewage may be carried up into the heart of the city.

The general results of these experiments accord fairly with those formerly obtained, so far as the length of the daily tidal oscillation is concerned, and they add important and novel information as to the distance to which the tidal currents may travel. For it is now evident that, at whatever time of tide the sewage is discharged, some of it may, under certain conditions, be carried up by the tidal oscillation alone into the heart of the Metropolis, and even farther.

Displacement of the sewage.

The Commissioners are of opinion that "the float experiments give no trustworthy information as to the gradual *displacement*, or progress downwards, of the sewage by the constant influx of fresh water," because "the resulting movement is so small that it is lost in the numerous irregularities to which the floats are subject in their travel." An estimate can, however, be made by calculation, "for, assuming the mass of water at any given place to be pushed bodily downwards by the influx of fresh water above, the mean displacement will be equal to the quantity of the inflow, divided by the area of the section." In times of heavy flood, the displacement might reach to 8¼ miles a day, whilst in dry seasons, it might be but little over $\frac{1}{4}$ mile a day. The average for ordinary seasons is about $\frac{2}{3}$ mile daily. Average $\frac{2}{3}$ mile.

The Commissioners ascribe considerable importance as regards the distribution of the sewage in the river to the *mixing* action which goes on between the sewage, the land or fresh water, and the sea water entering the river at its mouth. This mixing action is due to a variety of causes, the most important being the difference in specific gravity of these liquids, and their tendency to diffuse when brought into contact, aided by the irregularities in velocity and direction of the currents in different parts of the river. Mixing action.

This mixing action largely aids the tidal oscillation in carrying up the river sewage discharged at the main outfalls; so that, under certain circumstances, sewage so discharged may be carried over "almost the whole tidal range." The Commissioners consider it also proved, by calculations based on the chlorine test, that "the proportion of the sewer liquid contained in the river in the neighbourhood of the outfalls is, in dry seasons, very large. Some of the calculations profess to show that, in the driest weather, this proportion may possibly approach one-sixth of the whole volume of the river; but we may make a large deduction from this, and still find a startling result." One reason of this concentration is shown to be, that the river water into which the sewage is discharged is not pure water, but is water that by reason of the tidal oscillations has already become contaminated by the accumulation of successive previous sewage discharges. The only true sources of dilution for the sewage are the land water entering above and near Mixing action aids the tidal oscillation. Concentration of the sewage.

the outfalls, and the salt water which finds its way upwards from the sea.

The mixing action considerably facilitates the permanent progress of the sewage out of the river.

Sewage gets out to sea after thirty days' oscillation.

Instead of the $\frac{2}{3}$ mile displacement near the outfalls due to the fresh water alone, in the mean conditions, the mixing action may be stated to produce a permanent displacement of $\frac{8}{10}$ mile per day. In dry weather, the sewage discharged at the outfalls gets out to sea, after about thirty days' oscillation up and down. It may thus be said that by this natural process of mixing, the sea sends, so to speak, an auxiliary carrier up to the high parts of the estuary to help the land water in bringing the sewage down. There is one respect in which the mixing action is less beneficial, namely, that the combination of sewage with sea water produces less inoffensive compounds than with fresh water. The calculations show that in dry weather at high water, (when the sewage is discharged) there is a large proportion of sea water in the river; and it is clear, therefore, that the discharge of sewage into such a mixture must be liable to produce a greater nuisance than if running into a fresh stream. (*First Report*, *Royal Commission Metropolitan Sewage Discharge*, pp. 45-48.)

Large proportion of sea water in the river.

Formation of mud-banks.

No evidence was given before the Royal Commission on Metropolitan Sewage Discharge (1884) as to the existence of banks or shoals of mud, which could be attributed to the deposition of solid matters in suspension in the metropolitan sewage after discharge into the river. The decision, also, of the arbitrators appointed in 1879 to inquire into the origin of three particular mud-banks, situated near the outfalls, was favourable to the Metropolitan Board of Works, for they considered that the suspended matter in the tidal portion of the Thames was derived from a large number of sources, the proportion contributed by the metropolitan sewage being *small* as compared with the total amount of suspended matter in the whole volume of tidal water flowing past the outfalls on every tide.

But this decision loses somewhat of its force when it is considered that the sewage discharge, according to Dr. Frankland, adds to the river no less than a million and a quarter tons of mud every year (enough to fill up 300 yards of the river near the outfalls to low-water level); and it is hardly possible to believe that this vast mass of mud can all be carried in a state of suspension in the water out to sea; even the precipitation of a small portion of it at one or more spots might give rise to considerable banks of foul mud.

Amount of mud added to the river by the sewage.

The First Report of the Royal Commissioners on the Metropolitan Sewage Discharge is interesting as showing that even the enormous volume of metropolitan sewage may undergo considerable purification after its discharge into the river, provided there is sufficient fresh water in the river to dilute the sewage near the outfalls. We may quote the following passages from their Report (p. 62):—

Purification of the metropolitan sewage.

> On the whole the chemical analyses show that there is a progressively increasing impurity of the river from Teddington downwards to the outfalls, and then a decreasing impurity down to Gravesend, below which place the sewage is not perceptible. The oxygen dissolved in the water exhibits a corresponding decrease where the impurity increases, and *vice versa*. This shows not only the impurity of the water at and near the outfalls, but also that the oxygen does active work in oxidising and thus purifying the sewage impurities in the river. Besides the purification of the river by oxidation, there is evidence of its purification by means of animal and vegetable life. Animals of low type, notably *entomostraca* (such as water-fleas), feed upon the solid elements of sewage. These animals themselves excrete solid matters, but of course in a diminished amount; the balance is decidedly in favour of purification. Minute algæ and other plants of low organisation vegetate in the polluted reaches, and by giving off oxygen, they tend to promote the purification of the water. The net result of these complex processes—pollution by sewage, oxidation of the sewage, consumption by minute animals, and reoxygenation of the river by the action of vegetable life, and by renewed absorption of oxygen from the air—is that in cold weather and in cool wet summers the pollution of the river water exists indeed, but does not increase; the above processes being adequate to prevent that. But during hot dry weather the pollution increases, exceeding the purifying power of the agents for its removal; and the river then becomes a nuisance more or less great, and within greater or less limits.

Impurity of the river.

Decrease of oxygen.

Purification by animal and vegetable life.

Net result of these processes.

POLLUTION OF DRINKING WATER.

But, when the water into which sewage is turned is to be used afterwards for drinking purposes, considerations of a still more important nature as regards the health of communities arise. It is certain from what has already been seen, that water containing excretal matters cannot be used for drinking purposes without great detriment to health, and that it in some cases causes very serious diseases. But the question arises as to whether water of a river, which has received the sewage of a town some miles higher up, is purified during its course to such an extent that it may be used with impunity as a drinking water. The evidence collected on this head by the Royal Commission on Water Supply was very various. Dr. Frankland says—

Is the water purified during the flow of a river?

> There is no process practicable on a large scale by which that noxious material (sewage matter) can be removed from water once so contaminated, and therefore I am of opinion that water which has been once contaminated by sewage or manure matter, is thenceforth unsuitable for domestic use (p. 80).

Not fit to drink afterwards.

In another place he informs us that about four-fifths of the nitrogenous matter contained in fresh sewage is decomposed before the sewage, after a run of two or three miles, emerges into the river, and that the remainder "is decomposed with extreme slowness afterwards." In the First Report of the Rivers Pollution Commissioners, analyses are given which show this fact tolerably clearly. Experiments were made by taking samples of the water of different polluted rivers at various points, making correction where necessary for the influx of unpolluted waters. It appears that when the temperature does not exceed

Nitrogenous matters: partly decomposed soon; the rest very slowly.

63° Fahr. a flow of between 11 and 13 miles "produces but little effect upon the organic matter dissolved in the water." To remove all uncertainty from the "variability of the composition of the river waters at different times of the day," experiments were made by mixing filtered London sewage with water; "it was then well agitated and freely exposed to the air and light every day, by being siphoned in a slender stream from one vessel to another, falling each time through 3 feet of air." The mixture, which originally contained in 100,000 parts ·267 of organic carbon and ·081 of organic nitrogen, was found to contain, after 96 hours, ·250 of organic carbon and ·058 of organic nitrogen; and after 192 hours, ·200 of organic carbon and ·054 of organic nitrogen. The temperature of the air during this experiment was about 20° C. (68° Fahr.) "These results indicate approximately the effect which would be produced by the flow of a stream containing 10 per cent of sewage for 96 and 192 miles respectively, at the rate of one mile per hour." They show then that at the above temperature, during a flow of 96 miles, at the rate of one mile an hour, the amount of organic carbon was reduced 6·4 per cent, that of organic nitrogen 28·4 per cent; while during a flow of 192 miles at the same rate, the amounts of these two substances were only reduced 25·1 and 33·3 per cent respectively. It is shown that the oxidation of this organic matter is chiefly effected by the amount of atmospheric oxygen dissolved in the water, "such dissolved oxygen being well known to be chemically much more active than the gaseous oxygen of the air."

Experiments.

Extreme slowness of decomposition.

Action of dissolved oxygen.

It was found, however, that the action of this dissolved oxygen was not really anything like so quick

Slowness of oxidation.

or so perfect as generally supposed, and that 62·3 per cent of the sewage was the maximum quantity that would be oxidised during 168 hours, even supposing that the oxidation took place during the whole time at the maximum rate observed, which was certainly not the case. (*First Report, R. P. C.*, 1868, vol. i. pp. 18-20.)

Summary of results.

It is thus evident, that so far from sewage mixed with twenty times its volume of water being oxidised during a flow of ten or twelve miles, scarcely two-thirds of it would be so destroyed in a flow of 168 miles at the rate of one mile per hour, or after the lapse of a week. . . . Thus, whether we examine the organic pollution of a river at different points of its flow, or the rate of disappearance of the organic matter of sewage when the latter is mixed with fresh water and violently agitated in contact with air, or finally the rate at which dissolved oxygen disappears in water polluted with 5 per cent of sewage, we are led in each case to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness, even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage-matter becomes thoroughly oxidised. It will be safe to infer, however, from the above results, that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation.

Cannot be sure that the organic matter is thoroughly oxidised.

Mr. Simon's evidence before the Royal Commission on Water Supply, above referred to, shows that he holds the opinion which has been expressed in the above paragraph. He says, "It ought to be made an absolute condition for a public water supply that it should be uncontaminable by drainage." Dr. Angus Smith, while pointing out that the presence of nitrates and nitrites in river water is not a reliable test for previous sewage contamination, says that below Reading the Thames always contains organic impurities. Sir Benjamin Brodie says, "Medical statistics will tell you much more about the injurious or non-injurious character of sewage water than any analysis would do;" and he evidently considers that it is not safe to

A water supply should be *unconta-minable.*

Hygienic researches give the best evidence.

trust even to a long flow of contaminated water for the removal of the injurious organic matter contained in it; in fact, in his evidence given before the Rivers Pollution Commissioners (1857) he says (*First Report, River Thames*, vol. ii.; *Minutes of Evidence*, p. 49)—

Sir Benj. Brodie's opinion on the oxidation of the organic impurities.

I believe that an infinitesimally small quantity of decayed matter is able to produce an injurious effect upon health. Therefore, if a large proportion of organic matter was removed by the process of oxidation, the quantity left might be quite sufficient to be injurious to health. With regard to the oxidation, we know that to destroy organic matter the most powerful oxidising agents are required: we must boil it with nitric acid and chloric acid, and the most perfect chemical agents. To think to get rid of organic matter by exposure to the air for a short time is absurd.

Contrary opinions.

On the other hand, Dr. Miller considers that oxidation goes on in rivers to a very perfect extent, and that river water, after being contaminated with sewage, is safe for drinking purposes "in the majority of instances." *There may, however, be cases in which danger is present.* Dr. Letheby also is of opinion that the present water supply of London is a "thoroughly wholesome water," and that ordinary sewage mixed with its own bulk of water, after floating a dozen miles or so, is entirely decomposed, and there is "not a particle of that sewage to be discovered by any chemical process." The analyses above alluded to show that this is not the case. Dr. Odling and Mr. Hawkesley appear to have given the same opinion; and the evidence on this side prevailing over the more cautious opinion that it was certainly impossible to be sure that water which had been once contaminated was ever purified so as to be absolutely safe for drinking purposes, the Water Supply Commissioners came to the conclusion that there was no evidence to show that the water supplied by the London Companies

Conclusion of the Commissioners,

was not generally good and wholesome; and that they could not admit the possible presence of undetected germs of disease as a "conclusive argument for abandoning an otherwise unobjectionable source of water supply." But we have, in Mr. Simon's Report on the Cholera Epidemics of London in 1848-49 and 1853-54, sufficient evidence to show that the localities in which the cholera was especially prevalent were almost entirely determined by the degree of impurity of the water supply. When the Lambeth Company took its water from the Thames near Hungerford Bridge, the people who drank that water died at the rate of 12·5 per thousand. When the source of supply was moved to the Thames at Thames Ditton, the mortality was only 3·7 per thousand, while at the same time, and in the same districts, the mortality among the people who were supplied with water by the Southwark Company from the Thames at Battersea was at the rate of 13 per thousand. During the epidemic of 1866, the causes of which were inquired into by Mr. Radcliffe, the chief field of localisation was, on the contrary, north of the Thames, and especially in the eastern districts, where there were double the amount of deaths that occurred over all the rest of London, and five times the amount of deaths that occurred in the southern districts, which had not only since 1854 been supplied with better water, but had enjoyed a freer removal of sewage by the completion of the South Main Drainage Works. In effect, the area of explosion was found to be limited to the district supplied entirely with water by the East London Company, and not only so, but "to approximate with remarkable closeness to the limits of the districts supplied with water from Old Ford."

that the pollution of the water supply was not proved.

Cholera distribution determined by impurity of water.

South of the Thames.

East district, north of the river: 1866.

Cholera area districts supplied with water from Old Ford.

In the northern districts receiving water from the East London Company, and with one comparatively small exception from Lea Bridge, the number of deaths from the epidemic within this period was 4. In the southern districts, receiving water from Old Ford, the deaths from the epidemic were 391. The explosion, in fact, was confined to an area supplied with water by one particular company and from one particular source. (*Ninth Report, M. O. P. C.*, p. 300.)

The Registrar-General's evidence is also perfectly clear upon this head. He says—

Registrar-General's evidence from sub-districts.

Six districts are supplied from Old Ford, and every one has been ravaged by the epidemic. The other 31 districts have, for six weeks in succession, suffered slightly. The 37 districts are sub-divided into 135 sub-districts ; 21 are supplied with the same water, and have all suffered six weeks in succession ; 115 subdistricts have suffered inconsiderably. . . . By the doctrine of chances, it is impossible that the coincidence between this particular water and the high mortality should be fortuitous in 135 cases during six weeks in succession. The force of this induction extends over all the area of observation in previous epidemics where sewage water has so often led to cholera outbreaks.

Direct evidence of pollution of the water.

But Mr. J. Netten Radcliffe went farther than this, for he showed that the water delivered from the Old Ford covered reservoirs had been polluted with water from the filthy uncovered reservoirs. In fact, it was acknowledged by the engineer of the Company that at "the close of June or beginning of July—late in the former month or early in the latter—*water was drawn from the northern uncovered reservoir into the covered reservoirs to the depth of three inches, to supplement a defective supply from the filter-beds.*" More than this, it is the fact that on the 26th and 27th of June 1866, the discharges of the first two patients that died of epidemic cholera in the East districts were poured into the River Lea, "cesspool and canal," at Bow Bridge, about 600 yards below the northern uncovered reservoir ; and it is certainly a very probable assumption to make that the water in the old reservoirs got contaminated with cholera evacuations

Traced with great probability even to the first cases.

by soakage from this river-canal, the water of which, it appears, rose 2 feet 9 inches on the 29th and 30th of June, somewhat above the level of the uncovered reservoirs. This investigation was evidently carried out with such unusual care that no mere opinions can stand for a moment against it, and, taken in conjunction with Mr. Marshall's investigation of the cholera outbreak in connection with the water of the Broad Street pump in 1854, where it was shown that a special pollution of the water was the undoubted cause of the outbreak, and with Dr. Snow's investigation of the causes of some outbreaks at Wandsworth and other places in 1849, must be considered as affording a demonstration of the fact that cholera may be propagated to a frightful extent by the pollution of drinking-water with the evacuations of cholera patients.

Other evidence as to the propagation of cholera.

Enteric fever at Mevagissey

As a good example of the spread of enteric fever by the pollution of a stream used for drinking water with the discharges of a person suffering from this disease, we may mention the case of an outbreak at Mevagissey, a small town (population about 1800) on the south coast of Cornwall, which was investigated by the author for the medical department of the Privy Council. The arrangements for the removal of excrement were most inefficient, and in 1849 cholera caused 120 deaths there. A young man came home to a house in the upper part of the town, sickening for what proved to be enteric fever. His discharges were thrown into a privy which drained directly into the stream from which a part of the population obtained water for domestic purposes. The result was an outbreak of over 100 cases of the fever throughout the town. The houses around the public well and

How introduced.

deriving their water supply from it were almost free from the disease.

Evidence against *de novo* origin.

This instance affords a strong argument against the theory of the *de novo* origin of the poison of this disease, as excrement-polluted water was drunk by the inhabitants for many years without a case of enteric fever appearing, but when the dejecta of an enteric fever patient found access to the water, the disease spread with great rapidity.

Typhoid fever at Lausen.

The following account of an epidemic of this disease at Lausen is extracted from *Die Deutsch. Vierteljahrschrift. für. off. gesundheitspflege* (vol. vi. p. 154) :—

Outbreak of the fever.

In August 1872 there occurred in Lausen, a village of 780 inhabitants, in the Basle Canton, Switzerland, an outbreak of typhoid fever; the village having for many years been singularly free from that disease, and in fact from all epidemic diseases. About half a mile south of Lausen there is a small side valley, the Fürlerthal, separated from Lausen by a hill. In an outlying farmhouse in this valley a peasant who had lately been travelling away from home was attacked with typhoid fever on the 10th of June. On the 10th of July a girl in the same farm was seized with the fever, and later on the peasant's wife and child. Nothing was known of this outbreak in Lausen, when suddenly on the 10th of August 10 of the inhabitants became ill with the fever, in 9 days more the number attacked was 57, and in 4 weeks over one hundred were prostrated. Altogether, until the termination of the typhoid fever epidemic at the end of October, 130 people were attacked. On investigation it appeared that all the houses in the village whose inhabitants drew their supply of water from the public watercourse, were attacked by the disease, while six houses where the inhabitants drew water from their own private wells were exempt. The public watercourse arises from a spring at the foot of the hill on the side towards the village. There are some other farmhouses in the Fürler valley, but these escaped all infection. It appeared, therefore, that the spring was the source of infection. There could be no doubt that the Fürler brook was polluted by the evacuations of the typhoid patients, as it flowed by the side of the farmhouse, both from the privies and receptacles for night-soil, as well as from the washings of the clothes of the patients. Now ten years previously a hole suddenly formed close by the side of the brook below the farmhouse in which water was seen to flow, and for the sake of experiment the whole of the brook was diverted into this hole, when it disappeared under the

Fürler brook specifically polluted.

ground and was seen no more. After one or two hours the springs in Lausen, which were almost dry owing to drought, began to flow copiously, at first yielding a muddy water which later became clear, and continued to flow copiously until the Fürler brook was again turned into its original course and the hole filled up. On subsequent occasions when the fields below this spot were irrigated by damming up the Fürler brook, the springs in Lausen after a few hours began to yield a more copious supply. Between the middle and end of July in 1872 these fields were irrigated with the water which at that time was polluted with the excreta of the typhoid fever patients, and the springs in Lausen became more copious, the water being thick and foul tasting. Three weeks later the epidemic suddenly commenced in Lausen. Subsequently the experiment was retried of opening up the hole by the side of the Fürler brook and diverting the latter into it, when in three hours' time the yield from the Lausen springs was found to be doubled. A large quantity of salt was then dissolved in the water of the brook, and in a short time there was a most decided salt taste in the Lausen spring water; but on mixing flour very finely ground with the water of the brook, the solid constituents of the Lausen spring water were not increased, and not the slightest trace of a starch granule could be distinguished in it. These experiments were sufficient to show that the water of the brook passed through layers of earth, which served as efficient filters for solid particles like flour, but were not sufficient to destroy the infective germs of the typhoid evacuations.

Springs in Lausen more copious.

Water filtered through soil conveyed disease.

We may here quote a passage from the Sixth Report of the Rivers Pollution Commissioners (p. 221), which sums up accurately the lesson conveyed by the history of the above epidemic. "The investigation of the epidemic of typhoid fever at Lausen proves that even very efficient filtration does not prevent the propagation of that fever by water. Nothing short of abandonment of the inexpressibly nasty habit of mixing human excrement with our drinking water, can confer upon us immunity from the propagation of epidemics through the medium of potable water."

Propagation of fever by water.

Remarks.

With such evidence as this before us, and knowing that the water supply of most towns is derived (however undesirable it may be that it should be so) from rivers which have towns upon their banks higher up, it is difficult to understand how the admission of sewage into running streams is not by every one considered to be both disgusting and dangerous. We think the evidence that sewage is *worse than wasted* by being turned into a river is tolerably complete.

Conclusions of Rivers Pollution Commissioners.

The conclusions and recommendations of the Rivers Pollution Commissioners (*Sixth Report* pp. 427, 428) are of the greatest interest, and may here be given :—

As to the possibility of rendering polluted water again wholesome :

1. When the sewage of towns, or other polluting organic matter is discharged into running water, the suspended matters may be more or less perfectly removed by subsidence and filtration, but the foul organic matters in solution are very persistent. They oxidise very slowly, and they are removed only to a slight extent by sand filtration. There is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source.

2. Of all the processes which have been proposed for the purification of sewage, or of water polluted by excrementitious matters, there is not one which is sufficiently effective to warrant the use, for dietetic purposes, of water which has been so contaminated. In our opinion, therefore, rivers which have received sewage, even if that sewage has been purified before its discharge, are not safe sources of potable water.

As to the propagation of epidemic diseases by potable water :

1. The existence of specific poisons, capable of producing cholera and typhoid fever, is attested by evidence so abundant and strong as to be practically irresistible. These poisons are contained in the discharges from the bowels of persons suffering from these diseases.

2. The admixture of even a small quantity of these infected discharges with a large volume of drinking water, is sufficient for the propagation of those diseases amongst persons using such water.

3. The most efficient artificial filtration leaves in water much invisible matter *in suspension* and constitutes no effective safeguard against the propagation of these epidemics by polluted water. Boiling the infected water for half an hour is a probable means of destroying its power of communicating these diseases.

4. Other epidemics, such as dysentery and diarrhœa, are also probably propagated by drinking water, but the evidence is here neither so abundant nor conclusive as it is in the case of cholera and typhoid fever.

As to the improvement of water by filtration :

1. Sand filtration as carried out in water-works not only clarifies the water by removing suspended impurities, but also diminishes the proportion of organic matter in solution, to an extent dependent upon

the thickness of the filtering medium, and the rate at which the water passes through that medium.

2. Domestic filtration, as usually practised, is of little or no use; but, properly performed, it is much more efficient than sand filtration on a large scale, in improving the quality of water polluted by organic matters. The best materials for domestic filters are spongy iron and animal charcoal.

3. Although the improvement of excrementally polluted water by filtration may reasonably be considered on theoretical grounds to afford some feeble protection against the propagation of epidemic diseases by water, no trustworthy evidence can be adduced to support such a view.

Thames and Lee waters.

The Commissioners recommended that the Thames and the Lee should, as early as possible, be abandoned as sources of water for domestic use; and that the Government should in future withhold their sanction from all schemes involving the expenditure of more capital for the supply of Thames water to London.

Reduction of micro-organisms by filtration.

In a paper on "The Filtration of Water for Town Supply" read by Dr. Percy Frankland before the congress of the Sanitary Institute at York, 1886, it is stated that the number of micro-organisms in unfiltered Thames water at Hampton is reduced 97·7 per cent (average of 6 months' experiments) by passing through the sand and gravel filter beds of the water companies supplying water to London, and that this reduction depends on the storage capacity for unfiltered water, the thickness of fine sand used in filtration, the rate of filtration, and the renewal of the filter beds.

Are "pathogenic" organisms removed?

These experiments show that sand filtration, when properly conducted, is more efficacious in purifying water than was formerly believed to be the case. But there is no direct evidence to show that "pathogenic" or disease-producing organisms would be retained in the filter beds as are the majority of the harmless microbes present in water. Even if it were so, their removal by filtration would depend on the thoroughness with which the filtration was conducted, and past experience tends to show that failure in this respect must sometimes be looked for. It is necessary to remember also that Koch's method of cultivating micro-organisms on nutrient gelatine (the method pursued by Dr. Percy Frankland) can only demonstrate the existence of those micro-organisms which are capable of growing at the ordinary temperatures and in the particular material used as a nutrient. As to the proportion these form of the whole number existing in any sample of water, we at present know nothing.

Method of cultivation.

DISCHARGE OF SEWAGE INTO TIDAL WATERS.

The evils arising from the discharge of sewage into the estuaries of rivers have been already fully considered, especially in the case of the metropolitan sewage discharge into the tidal waters of the Thames at Barking and Crossness. The circumstances productive of these evils may be briefly summed up as follows:—

1. Length of time before the sewage reaches the sea, causing, in dry weather, considerable concentration of the sewage in the river, forming what has been not inaptly termed a "sewage zone," due to the oscillation of the tides; and where the sewer outfalls are, as at Barking and Crossness, about 30 miles from the open sea, the resulting evil is of very great magnitude.

Formation of a "sewage zone."

2. Sewage discharged any time after high water will be carried up by the flowing tide above the outfall; and at the commencement of spring-tides the sewage so discharged will be carried up higher and

Sewage carried up above the outfalls.

higher by each flowing tide, until, as may be inferred from float experiments conducted for the Royal Commissioners on Metropolitan Sewage Discharge, the river water 20 miles above the outfalls may become tainted with sewage.

Sea water hinders oxidation.

3. The effect of the sea water in a tidal river is to cause, by the action of the various salts contained in it, a considerable precipitation of the organic matter in the sewage; the process of oxidation and purification is also lessened by the presence of these salts; so that besides a greater tendency to the deposit of mud, the purification of sewage discharged into mixed salt and fresh water is considerably slower than if discharged into fresh water only.

Discharge of sewage into the sea.

At certain towns situated on or close to the sea-shore, where land cannot be obtained for disposal of the sewage by irrigation, or where the land available for such a purpose is situated much above the level of the town, so that the sewage would have to be pumped to a considerable height, its discharge into the sea may be the least costly to the town authorities, and if certain conditions are fulfilled by which the sewage is carried out to sea, so as not to return with the flow of the tide, and become a nuisance by being deposited on the foreshore, this method, especially in the case of health resorts, may be the one most suited to the general interests of the town.

May create a serious nuisance.

In numerous instances, where these conditions have not been observed, the sewage disposal has been the cause of nuisance and injury to the health of the inhabitants; in the case of several sea-side health resorts the evils having been sufficiently great to damage their reputation for healthiness and keep away intending visitors.

In every case the outfall of the discharging sewer should be below the level of the water at all states of the tide, and be provided with a tidal valve, to prevent the ingress of sea water. The position of the outfall should be so chosen that, if possible, the sewage will be always carried out to sea, independently of the tides, and the possibility of its return avoided; and for this purpose, advantage should be taken of any current that flows off or along the shore, the sewage being discharged into it, and thus carried away from the neighbourhood of the town. If there is a current setting along the shore, then the sewer outfall should be placed at that extremity of the town which will prevent the sewage being borne along the whole sea front. The prevailing winds must also be taken into account, so that floating matters may not be blown back towards the town.

Conditions necessary for success.

Should the town be situated at so low a level that the sewer gradients are small, and the sewage tide-locked for some hours of each tide, it will be necessary to provide a length of oval "tank sewer" outside the town, of more than sufficient capacity to store the whole of the sewage which flows from the town during the tide-locked period. In such a case, the velocity of the sewage being small, the town sewers tend to become "sewers of deposit," decomposition and evolution of gases ensue, and no amount of ventilation will quite obviate the nuisance arising. It may then be necessary to have recourse to storage in tanks at the outfalls and to pumping, or possibly the system of raising sewage by means of tidal power, as patented by Mr. C. Maynard Walker, may here have a useful application.

"Tank sewer" may be necessary.

Storage tanks and pumping.

In this system a large air-tight tank B is constructed, of sufficient capacity to contain half a day's

Raising sewage by means of tidal power.

flow of sewage, and placed at such a depth as to allow of a gradient being given to the sewers sufficient to render impossible sewage deposit and its attendant evils. The sewer enters the tank just above its floor, the opening being closed by an air-tight valve. Connected with the tank B by a curved pipe is another air-tight tank A, of double B's capacity, placed at a somewhat higher level. This tank has a discharging-pipe into the sea, protected by a valve, and is filled by another pipe from the sea, at high water. A third tank C, of the same capacity as B, is placed at the same level as A, and is connected with B by a pipe, which has its lower end open just above the floor of B, and its upper end open just under the roof of C. From the roof of C rises a ventilating-pipe open to the air, and from the floor a discharge-pipe protected by a valve opens into the sea. The working of this arrangement is as follows:—The tank B is filled with sewage, the displaced air escaping through the curved pipe, the empty tank A, and its supply-pipe into the outer air. As the tide rises the tank A becomes filled with sea water, and the displaced air, finding no means of escape, is compressed, and acting through the curved pipe forces the sewage in B up to C, the air in C escaping through its ventilating-pipe. As soon as the tide falls low enough the sewage in C escapes through its discharge-pipe into the sea, and the water in A also escapes. The tank B is again filled with sewage and the process recommences. Thus the sewage is discharged twice a day on the ebbing tide.

It is impossible to discuss fully the merits of this plan, as it has not yet undergone the test of actual experience, in which unforeseen difficulties may arise.

The opinion generally held that sewage by being discharged into the sea or into rivers is wasted, is controverted by Sir John Lawes, who holds that the sewage is "utilised to a certain extent by the fish feeding upon that which the sewage produces." The animalculæ which feed upon sewage become in turn the food of fish. The sewage which is discharged into the Thames he considers to be at first more suitable for animal than vegetable life, and it is "through the influence of innumerable forms of animal life that it becomes food for vegetation," this vegetation becoming in turn food for fish. Sewage a food for fish.

Notwithstanding the fact that the sewage discharge at Barking and Crossness has driven all kinds of fish very much lower down the river, Sir John Lawes says "there cannot be the least doubt that the removal of the sewage from the river, or even the removal of the sedimentary portion by means of lime, would be followed by a most serious reduction in the present quantity of fish."

Speaking of the metropolitan sewage he says, "Looking at the great cost which must be incurred before the sewage could be employed beneficially upon land, it is quite probable that, as a source of national wealth, its value is greater in its present state than it can be by any other process applied to it." (*Minutes of Evidence*, vol. ii. p. 73; *R. C. M. S. D.*) Value of sewage in the sea.

We know, however, that great injury has been done to the fishing interest in the Thames itself, for the fish have been driven down below Gravesend by the sewage discharge (see *ante*, p. 280). It is a mere hypothetical assumption that the withdrawal of the sewage from the river would be followed by a reduction in the quantity of fish in the sea, and one which

Number of fish in the sea cannot be affected.

seems sufficiently improbable when we are told by Professor Huxley "that the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea fisheries, are inexhaustible; that is to say that nothing we do seriously affects the number of the fish." (Address at the Inaugural Meeting of the Fishery Congress, 1883.)

Letter to the *Times*.

In a letter to the *Times* of 29th December 1884, Sir John Lawes reproduces the arguments as to the influence exerted by the sewage of London on the production of fish in the sea, which were contained in his evidence before the Royal Commission on Metropolitan Sewage Discharge.

Mr. Fryer's reply.

With this letter should be read one by Mr. Charles E. Fryer of the Government Fisheries Department, which appeared in the *Times* of 3d January 1885. Mr. Fryer in this letter says "the fishery of all others that has shown the most marvellous growth is the Scotch herring fishery, which has always been prosecuted far from the influence of sewage discharge, and is every year being carried on more and more successfully at a greater distance from the shore. If sewage or any other artificial stimulant were required to maintain the productiveness of any of our fisheries against possible exhaustion, the herring fisheries would surely have been the first to show signs of the need."

Scotch herring fishery not being exhausted.

Fertility of the soil and the fertility of the sea.

The analogy drawn by Sir John Lawes between the fertility of the soil and the fertility of the sea he shows to be fallacious, for "the removal of so many tons of adult fish capable of devouring their neighbours and of living on the other food which the sea supplies is only so much relief to the drain on the fertility of the sea which their presence would entail," and cannot of course be compared to the exhaustion of the productiveness of a soil by repeated cropping.

Finally Mr. Fryer proceeds to show that the 600,000 tons of fish annually brought ashore—for the abstraction of which from the sea Sir John Lawes calculated that the sewage of London would afford a direct compensation—are collected from an area of about 150,000 square miles, with a maximum depth of about 350 feet. "How," he asks, "are the constituents of London sewage to be spread with anything like uniformity over this vast area? What proportion of those constituents will the various marine fauna and flora receive? If Sir John Lawes had proposed that the sewage of London should be carried into the middle of the German Ocean, when the action of the winds and tides and currents would have spread it in various directions, giving the fish the opportunity of eating what they wanted and rejecting the rest—which I fancy would be the greater portion—I could have understood that some advantage might accrue." The advantage being that the sewage, "instead of fermenting and becoming putrid in the narrow estuary of the Thames," would be dissipated harmlessly, with little risk of either water being poisoned or of sea-bottom being silted up with noisome slime.

Size of area from which the fish are collected.

How is the sewage of London to be spread over this area?

CHAPTER IX

TOWN SEWAGE—STRAINING AND PRECIPITATION

Absurdity of throwing away manure.

It being certain that artificial manures, or guano brought from an enormous distance, cannot be always relied upon to furnish a sufficient supply for the cultivation of our land, we must keep in view the obvious absurdity of turning so much valuable matter as the sewage has been shown to contain, into the sea or into rivers, an absurdity pointed out by Parent Duchatelet when he says—speaking against the formation of drains between the cesspools and the sewers so as to get rid as fast as possible of the contents of the former by emptying them into the Seine—"one would lose by this method an enormous mass of manure which our agriculture requires, and the value of which, even now considerable, cannot fail to increase," adding that this proceeding would also be received with repugnance by the people, who are persuaded that they are supplied with the water of the Seine for drinking purposes. All the earlier forms of disposing of excreta have more for their object the utilisation of the manure than the speedy removal of filth from the vicinity of habitations. This removal having now been in every way encouraged by the connection of privies and closets with the sewers, in spite of the fact that it was before 1815 penal to do

Removal of filth encouraged by connecting closets with the sewers.

so, and being now furthered by the substitution of water-closets for privies on a very large scale throughout the kingdom, it has become necessary to see how the valuable matters, thus as it were thrown away, may be on the one hand prevented from polluting the rivers, and on the other utilised in the most profitable manner possible for agricultural purposes.

As sewage contains a great amount of suspended matters, it is natural that the first attempts at purifying it should have been by allowing it to stand so that these matters might be deposited and the water be allowed to run away in a somewhat purer condition at any rate; but the suspended matters will not subside in this way to any great amount, or they do so only very slowly, so it was found necessary to resort to Subsidence.

SIMPLE FILTRATION, OR STRAINING

in order to separate them from the liquid part: in this way a semi-solid mass of black mud was obtained, which was mixed with ashes or with street sweepings and sold as manure, while the liquid part, containing all the soluble constituents and part of the suspended ones, was allowed to flow away in a comparatively clear and inoffensive condition into the nearest water-course. Simple filtration,

"This liquid, however, still contains animal and vegetable matters in solution, and is anything but *water;* it is also liable to speedy putrefaction and consequent noxious smell, with the production of a further quantity of suspended matter, rendering it again, though in a less degree, turbid. In addition to organic matter, the filtered liquid contains of course all the soluble mineral compounds of the sewage, and in most cases is charged with carbonic acid, and with more or less sulphuretted hydrogen, both of these being products of the decay of vegetable and animal matters." (Professor Way, *Second Report of Sewage of Towns Commission*, 1861, Appendix No. 6, p. 65.) not successful as a method of purification.

In some towns this straining process is still resorted to (1872).

Examples of this plan.

An imperfect sort of filtration is practised at Ely, where the solid soil is separated from the sewage by upward filtration, while the liquid part enters the river below low-water mark, of course containing all the soluble impurities. "The solid part is taken out in the winter, mixed with the town ashes and road scrapings, and a bulky manure is obtained, which sells for 2s. 6d. a cubic yard, and pays in great measure for the expense of dust-removal and labour. Opinions differ as to whether any considerable nuisance arises from the outlet works or the muck-heaps. No complaint comes of nuisance in the river."

Manure sells readily, but is not valuable.

At Rugby, the part of the sewage that is not used for irrigation falls on a series of filtering-beds from which the fluid part runs off in a comparatively clear state into the Avon. "There is no difficulty in disposing of the black solid matter on the filters at half-a-crown a load."

At Ashby-de-la-Zouch, solid matters are separated by subsidence in a tank, and by filtering through upright screens; the liquid overflow runs into the brook; "a black rich-looking mould taken from the filtering-tanks is bought with avidity by the farmers." The water of the brook, after receiving the liquid matters, is occasionally used for irrigation.

At Banbury, the sewers empty into settling tanks and filters from which the liquid part flows off into the Cherwell, "and the solid part is mixed with town sweepings and ashes, and sold for manure. . . . At the outfall works carbolic acid and perchloride of iron have been used to further purify the filtered sewage, and to prevent complaints of the pollution of the

Cherwell. Nevertheless, nuisance from the river is complained of, and law proceedings have lately been taken in respect of it: any such nuisance is outside the town." Nuisance to river.

At Chelmsford, filtering-tanks were constructed, separating the solid part—which was mixed with the town ashes and sold to neighbouring farmers—from the liquid, which was discharged into the river. This is, however, now done away with, and the whole of the sewage employed in irrigating some land near the town. (*Ninth Report M. O. P. C.*, pp. 163, 168, 203, 142, and 156.)

As this straining obviously does not purify the sewage, though it may still have a valuable application, as we shall hereafter see, many attempts have been made to precipitate the valuable constituents by means of chemical reagents: these form the so-called

"PRECIPITATION PROCESSES."

Some of the more important of them are the following:—

The *lime process* "has been applied to sewage upon an extensive scale at Tottenham, for the manufacture of 'Tottenham Sewage Guano'; at Blackburn, and especially at Leicester, in the production of the so-called 'Leicester bricks.'" In the Ninth Report of the Medical Officer of the Privy Council it is stated that at Leicester "the elaborate outfall works succeed in their object of purifying the river from nuisance. The river used to be very foul, showing a frothy surface and all sorts of colours where the sewage was discharged. Now, with far more sewage discharged, there is only a little discoloration just at the outlet. Lime process. Purification of river at Leicester.

The fish have come back too; there were none in the river for two miles down" (p. 75). The process consists in the admixture with the sewage of a certain proportion of milk of lime, after which "a copious deposit of highly putrescible mud takes place, while the supernatant liquid flows off in a comparatively clear though somewhat milky condition."

Method of procedure.

"The solid matter which is precipitated to the bottom of the reservoirs is worked back by an Archimedean screw, and thence raised by a string of buckets into troughs on the top of the building, from whence it is conveyed by gravitation into reservoirs prepared to receive it, where it lays until the supernatant water drains off, and the solid matter is disposed of as manure."

Result.

Professor Way found from his experiments that from fifteen to sixteen grains per gallon of slaked quick-lime were sufficient to precipitate ordinary sewage, and that no element of agricultural value was preserved by it except the phosphoric acid, of which five-sixths were precipitated.

The Sewage Commission reported that the process, "though very simple, and the least costly of any," could not be profitable in an agricultural sense, and did not purify the sewage. (*Second Report S. of T. C.*, p. 15.)

The Rivers Pollution Commissioners (1868) examined this process both at Leicester and Blackburn. They say:—

Failure to purify rivers.

At both places the method obviously failed in the purification of the sewage to such an extent as to render it admissible into a river. At Blackburn especially, the river below the outlet of the limed sewage was in a most offensive condition of putrefaction, our note made at the time of our visit being as follows:—" Horribly offensive, turbid, blackish stream, disengaging most offensive gases, with black masses of putrid mud floating on the surface." (*First Report R. P. C.*, vol. i. p. 52.)

The analytical examinations made showed that the suspended matters were removed to a very considerable extent, 57·56 parts in 100,000 being reduced to 6 on one day, 48 parts to 2·8 on another, and 59·88 to 6·56 on a third; that of the total solid matters in solution, a quantity varying from ten to twenty parts in 100 was removed; that about a quarter of the organic carbon, and from 54·48 to 65·79 per cent of the organic nitrogen were removed, except on the third day, when the amount of organic nitrogen in solution actually increased; "that is, the amount of organic nitrogen dissolved from the suspended matters of the sewage was greater than that precipitated from solution by the chemical reagents added." With regard to the ammonia, its amount remains about the same, or has actually increased; so that the water which is sent into the river not only contains most of the valuable constituents of the sewage, but contains about half of the *putrescible* organic matter, which is precisely the substance that it is required to keep out of rivers. The manure produced is less valuable than might be expected, for the mud, being alkaline, loses ammonia while drying. Effect on the sewage. Manure loses ammonia.

Its value has been variously estimated at from 12s. 9d. to 17s. per ton, the latter estimate being certainly too high. The above-named Commissioners consider it to be worth 13s. 6¼d. It is stated that "an exaggerated notion of the agricultural value of the sewage manure has led to a reaction among farmers, who now take away the semi-solid manure sparingly at 1s. a ton, while the working expenses of its production amount to 3s." (*Ninth Report M. O. P. C.*, p. 75.) Its theoretical and practical value.

The Rivers Pollution Commissioners remark:— "In all these places the plan has been a conspicuous Failure of the process failure, whether as regards the manufacture of valuable manure or the purification of the offensive liquid."

A *modification of this process* is in use at Northampton:—

Lime and chloride of iron.

Each million gallons of sewage is here mixed with twelve bushels of lime and about six gallons of chloride of iron; in hot weather more, in cold weather less. The lime is added first, and then the chloride of iron. The defecated sewage is afterwards submitted to upward filtration through a stratum of calcined iron-ore eight inches thick; but we consider that beyond the separation of suspended matters, which would be equally effected by subsidence, this latter operation is nearly useless. (*First Report R. P. C.*, 1868, vol. i. p. 68.)

Successful deodorisation,

In the Seventh Report of the Medical Officer of the Privy Council, it is stated that the deodorisation produced by this process was very perfect, and that a complaint which was directed against the sewage works, to the effect that they were a nuisance, was unfounded. (*Loc. cit.* p. 526.)

but river is polluted.

Result on sewage.

The effluent water runs into the river Nen, and although putrefaction is deferred by the presence of the iron salt, it ultimately takes place and fouls the river, so that an injunction has been granted by the Court of Chancery that this discharge into the river shall no longer take place. The result of the treatment appears to be, that the suspended matters are almost entirely removed, together with about one-sixth part of the ammonia, and rather more than a half of the organic nitrogen. It is plain, in fact, that the only advantage of the chloride of iron is to delay the pollution of the river for a short time, but not in any way to prevent it.

Persalts of iron,

Some experiments with *perchloride of iron* alone were undertaken by the Sewage Commissioners at Croydon. They concluded that it was a very valuable precipitant, in that when added to the sewage and neutralised by an alkali, a large flocculent precipitate of peroxide of iron was formed, which carried down all the suspended matters, with some of the dissolved organic matter; that it fixed the sulphuretted hydrogen and phosphoric acid, and gave solid and liquid residues, neither of which were noxious or likely to be so. (*Second Report S. of T. C.*, p. 17.)

Professor Way's experiments, however, showed that "this process cannot boast, any more than those formerly described, of any power of separating ammonia or other manuring material." (*Loc. cit.* p. 72.) not successful.

The chloride of iron is also too expensive, and so the process has been abandoned. Salts of zinc and of manganese have been proposed for the same purpose, and with a like result.

The Committee of the Local Government Board on Modes of Treating Town Sewage investigated the *"M and C" process*, which in 1875 was in use at Bolton-le-Moors. The details of this process with analyses of the manure produced are given in an Appendix to the Report of the Committee (pp. 38-41). The process is stated to be identical with that of Mr. Goodall, which had been tried at Leeds. The "M and C" process.

In carrying out the "M and C" process there is added to the sewage to be purified a mixture consisting of the following ingredients:—lime, carbon (a waste product of the prussiate of potash manufacture), house-ashes, soda, and perchloride of iron. The materials are mixed in a "pit," and lifted therefrom by means of a dredger into a second mixing pit, from which the mixture is discharged slowly into the sewage, as it flows through the works into two depositing tanks, each divided into three compartments, after which the treated sewage flows for a short distance along an open conduit, and thence into the river Croal. The tanks are cleaned out every fortnight, and about 70 tons of "sludge" are removed therefrom and thrown into heaps at the side of the tanks to part with the moisture which it contains, but it has been found impossible to dry it without applying artificial heat. Drying the sludge.

The cost of working the "M and C" process was stated by the manager to be less than that of the "A

B C" process. The Committee express their opinion that "the 'M and C' process, like its twin the 'A B C' process, merely removes the grosser parts of the suspended matters in sewage, but fails to remove the putrescible organic matters in solution, and therefore the clarified sewage cannot be admitted into rivers without causing pollution." This statement is conclusively proved by the results of the analyses of the "M and C" manure and effluent, made by Professor (now Sir Henry) Roscoe, who reports :—

The clarified sewage would pollute rivers.

Analysis of the effluent.

As regards the results of this analysis, it appears that the water, as compared with London sewage, contains about half as much animal refuse or products of animal decomposition. As regards the inorganic portion, this water contains considerably more than the London sewage does. These animal impurities are not completely got rid of by oxidation: and on keeping, the water has a putrescent smell; it cannot therefore be said that the process, whatever it may be that the sewage has undergone, has done much to render the effluent water innocuous.

Theoretical value of the manure.

The manure contained but a very small quantity of total nitrogen (less than 1 per cent) and no soluble phosphates. If dried, to leave only 15 per cent of moisture, its theoretical value would be £1: 1s. per ton.

General Scott's sewage-cement process.

The Committee of the British Association on the Treatment and Utilisation of Sewage investigated *General Scott's sewage-cement process* as carried on at Ealing (*Report* 1872, pp. 138-142). The following details as to the working of that process are taken from their report :—

Lime and clay are added.

Sludge burnt.

The principle of General Scott's process is to arrest the flow of the sewage by tanks, the suspended matters being precipitated by means of lime and clay, which are added to the sewage in the sewer previous to its arrival at the tanks, the proportion of lime so added being about 10 cwt., and of clay 5 cwt., to 400,000 gallons of sewage. After the sludge has sufficiently accumulated in the tanks it is drawn off, placed in a kiln, and burnt by intense heat, and then ground into cement.

Effluent water.

The effluent water, it is stated, "passes off very much clarified, and without any offensive smell at the time of discharge." The burning of the deposited matter, with the mixture of lime and clay, "renders the cement perfectly inodorous, and is one of the means by which the difficult question of the disposal of the precipitated sludge from sewage may be solved; and the method is one which may be adopted in cases where sewage cannot be used for irrigation in its crude state."

Cement inodorous.

The Committee inspected the works at Ealing several times. On one occasion, in July 1872, the weather was very hot, but it was found that the process was proceeding without any nuisance whatever, although the depositing tanks were not of sufficient capacity. The Committee remarked that one of the chief difficulties attending the process is the drying of the precipitated sludge with sufficient rapidity. If this is done by heat, it is liable to cause a nuisance, and is besides far too slow in action. By the use of filter-presses, introduced within the last few years, sewage sludge can be compressed into compact cakes, containing only 50 per cent of moisture. By this means the sludge precipitated by General Scott's process would be rendered dry enough to burn into cement. As regards the purification of the sewage by Scott's process, it would appear that—

Difficulty in drying the sludge rapidly.

Filter-presses.

By it the suspended matters are precipitated very completely: as to the more important constituents of the sewage, it is seen from the analyses that the effluent water contained rather more than two-thirds of the chlorine and three-fourths of the dissolved nitrogen of the sewage; but it must be remarked that the dissolved nitrogen appears in a different way in the effluent water and in the sewage; the actual ammonia is reduced to one-quarter of its amount, while the organic nitrogen, doubtless from solution of some of the nitrogenous suspended matters, is nearly doubled in amount in the effluent water. Some oxidation, too, has taken place, by which nitrates appear in the solution. Such water would be much too impure to be sent into a river, and too valuable to be wasted; indeed it is not pretended that the

Condition of the effluent.

"Too impure to be sent into a river, and too valuable to be wasted."

process is capable of *purifying* the liquid sewage; its object is merely the separation and deodorisation of the sludge (which, in the majority of cases, must necessarily be removed before the sewage can be utilised), and its ultimate use as fuel in the manufacture of cement.

When tried at Birmingham, General Scott's process was not found to be remunerative, and was very soon abandoned.

Carbolates and sulphites.

Carbolates of lime and magnesia (Macdougall's powders) have been proposed, but chiefly as disinfectants of the sewage. If added to the lime process they merely assist in delaying decomposition, but do not prevent it ultimately; the same may be said of the *sulphites of lime and magnesia*, which however at the same time decompose the sulphuretted hydrogen.

Chloride of magnesium with lime and tar.

Hillé's process was tried at Wimbledon; it consisted in the addition to the sewage of a mixture consisting of 100 lbs. of lime, 6 of tar, and 12 of calcined chloride of magnesium, with a certain quantity of some other substance of the nature of which we were not informed; the lime is slaked, and while it is hot the tar is added and thorougly incorporated with it; after the addition of the magnesian salt, etc., and sufficient water to make the mixture flow through a large tap, the whole is thoroughly stirred up together.

The sewage of about 5000 people, being about 180,000 gallons a day, was received into a small tank into which the precipitating mixture ran continually from the vat in which it was mixed; thence the sewage, completely deodorised, passed into a circular tank 20 feet in diameter, where the deposit settled while the effluent water was filtered through a basket containing 9 inches of charcoal into a small tank, whence the overflow passed into another, and thence into the brook, or rather ditch.

The deposit was taken out of the large tank twice a year; it was a thick black mud, slightly offensive when fresh, and has not been found valuable as a manure. *Deposit of little value.*

Two mixings of the above quantities of the precipitant were required per diem, and the cost of working the process was 6s. 3½d. a day without labour, and 5s. 6d. a day for the labour of two men. *Small costs.*

The chloride of magnesium was imported from Germany, and cost £8 a ton, delivered; it is a refuse from salt works, and could doubtless be got cheaper in England; the process is self-acting during the night, and might be to a great extent made so during the day; certainly a much larger amount of sewage could be managed at the same cost for labour.

This is then a deodorising process, which does not profess to recover a valuable manure from the sewage, but to purify the effluent water so that it is inoffensive, and to do this in the cheapest possible manner. *Summary of results.*

It therefore entails an almost entire loss of the valuable constituents of the sewage, and the effluent water doubtless contains, as that of all the other precipitation processes does, organic matters in solution, ammonia salts, etc., and cannot be supposed to be so purified as to be admissible into a stream which afterwards supplies drinking water.

Practically the same process is now in operation at Tottenham. The effluent flows into the Lea.

A process of treating sewage by *black ash waste* was described by Mr. Hanson, its inventor, to the Royal Commissioners on Metropolitan Sewage Discharge (vol. ii. p. 97). This process consists in exhausting black ash waste with water in tanks, the solution thus obtained being added to the sewage in *Hanson's process.*

Black ash waste.

the outfall sewer before reaching the reservoirs. Black ash waste is a waste product produced in the manufacture of soda. Its exact composition is unknown, but it probably consists of salts of soda together with sulphide of calcium. To the latter substance it probably owes the property claimed for it by Mr. Hanson of absorbing oxygen from the air, and of parting with this oxygen (if such indeed be the case) to the organic matter of the sewage. For this reason also the black ash waste must be old and not freshly prepared. New black ash waste will give off sulphuretted hydrogen and will not purify sewage.

In use at Aldershot.

The process is in use at Aldershot, but the sewage is treated as well with lime to remove the suspended matters. Mr. Hanson proposes to treat the metropolitan sewage with the black ash waste liquid without the addition of lime. In this case all the suspended matters of the sewage would pass into the river as now; but he claims that the sewage would be purified by oxidation and that the large amount of chlorine contained in the waste liquid would have the effect of causing the sewage to mix readily with the salt water in the river. The exhausted black ash waste would have to be carted away from the tanks, and might be used to raise low-lying land.

An oxidation process.

The principle of this process is different from the other chemical processes of treating sewage, inasmuch as oxidation and not precipitation of sewage matters is aimed at. Of its efficiency we are unable to speak, but it is certain that the supply of black ash waste, an unsaleable product, is almost unlimited, and for this reason the process should be a cheap one. It seems doubtful, however, to say the least of it, whether any process which does not at any rate remove the suspended matters of sewage can be practically an efficient process of purification.

A process, in which *super-phosphate of magnesia* is the essential precipitating ingredient, has been proposed and tried at various times both in this country and in France. In this country it is known as *Blyth's process.* The plan of it was to add a salt of magnesia, and some super-phosphate of lime, or super-phosphate of magnesia and lime-water, to the sewage, and it was thought that the triple phosphate of magnesia, ammonia, and water would be thrown down in an insoluble condition. Had this been the case it would have been, no doubt, an effective and valuable process, and it was even suggested that the magnesian rocks in various countries should be utilised by this process. (Bouchardat). It was, however, unfortunately found that the salt above mentioned is only insoluble in water containing an excess of ammonia. Blyth's process.

In fact, Professor Way's analyses show that by this no more ammonia is separated from sewage than by the foregoing processes, "whilst a third of the phosphoric acid added in the processes is left in solution, and constitutes an absolute loss to that extent." And the Sewage Commissioners reported that "without accomplishing any part of its intended object, it is the most costly of all the plans that have been proposed." (*Second Report S. of T. C.*, pp. 72, 15.) Very unfavourable result. Very expensive.

Holden's process, which was originally a French plan, is described in the Rivers Pollution Commissioners' First Report; it consists in adding to the sewage a mixture of *sulphate of iron*, *lime*, and *coal dust* (clay is also mentioned by the patentee), and allowing it to flow through a series of subsidence tanks, so that a deposit may take place. The result of the examination Holden's process.

of this process shows that while it "separates the whole of the suspended matters, it not only fails to remove the putrescible organic matters in solution, but actually (as measured by the organic nitrogen contained in these organic matters) increases their quantity. This it does by causing some of the putrescible organic matter in suspension in the original sewage to pass into solution. The effluent water could not therefore be admitted into rivers without causing pollution." It further appears that the amount of sulphate of lime in the effluent water is so great as to give it a very objectionable amount of permanent hardness. As to the manure produced, 100 parts of it only contained ·555 of organic nitrogen, ·004 of ammonia, and ·3 of phosphoric acid : "a manure of the above composition may be considered as practically worthless." (*First Report R. P. C.*, 1868, vol. i. p. 60.)

Increases putrescible matters in solution.

Worthless manure.

Phosphate process.

The *phosphate process* of Messrs. David Forbes, F.R.S., and A. P. Price, has been experimented upon at Tottenham.

It "consists in treating the sewage with a solution of the native phosphate of alumina dissolved in sulphuric or hydrochloric acid. This solution is in itself a powerful antiseptic and disinfectant, completely arresting further putrefaction, and depriving the most fœtid sewage of its offensive smell, causing at the same time the supernatant water to be clear and colourless, even if tinctorial substances of great intensity be present in the liquid." (*The Phosphate Process for the Utilisation of Sewage*, by David Forbes, F.R.S.)

Preliminary to irrigation.

It is suggested that the process in this stage would be a valuable preliminary to irrigation, as the offensive suspended matters would be precipitated, while the supernatant water would contain, besides dissolved organic matters and ammonia, a considerable quantity of soluble phosphates, so necessary for general farm crops. If, however, irrigation be not resorted to, the process is completed by the addition of a sufficient quantity of milk of lime to neutralise the liquid and precipitate the phosphates in solution.

Addition of milk of lime

The native phosphate of alumina (containing from 30 to 40 per cent of phosphoric acid, equal to from 65 to 87 per cent of tribasic phosphate of lime) costs £3 : 10s. a ton; it requires to be pounded and treated "with sulphuric acid in the proportion of one ton of the phosphate to from 12 to 14 cwts. acid." It thus forms a brown stiff paste, which is dissolved in water and allowed to flow into the sewage.

It is stated that "although in some cases less than half this quantity was found to be sufficient, the actual amount now employed on the large scale at the Tottenham sewage works is in the proportion of one ton of the crude phosphate to 500,000 gallons of sewage."

Proportion of phosphate to sewage.

With regard to the precipitate and its value as manure, an analysis by Dr. Voelcker shows it to contain 28·52 per cent of phosphoric acid, and 20·11 per cent of "organic matter and water of combination," containing, however, only 0·57 per cent of nitrogen, equal to 0·69 per cent of ammonia.

Dr. Voelcker says of it:—"It possesses valuable fertilising properties, and, in my opinion, a sewage manure equal to the sample analysed by me will command a ready sale at £7 : 7s. per ton." It must be remembered, however, that its chief value is due to the phosphoric acid which is put into it; indeed, as Mr. Forbes himself says—

Value of precipitate.

It is not pretended that this process extracts anything like the entire fertilising ingredients contained in the sewage, since it is admitted that by far the largest portion of the ammonia present in the sewage flows off with the effluent water, and is consequently lost unless this water is employed for the purpose of irrigation.

Ammonia lost.

The precipitate is in itself, however, a valuable manure, which is mainly owing to the most important and characteristic feature of the phosphate process, in which it differs from all processes now in use, which is that the substances employed in effecting the purification of the sewage are only such as augment greatly the agricultural value of the precipitated deposit, which can be increased at pleasure by merely adding more of the phosphate, so that it can by this means be rendered sufficiently valuable to bear the cost of transport to a distance from the seat of manufacture. (*Loc. cit.* p. 11.)

Value of deposit due to phosphate employed.

It is then admitted that all the ammonia, and at any rate part of the organic matter in solution, are left in the effluent water, and what remains to be seen is if any, and if so how much, of the phosphoric acid added goes away in the effluent water. It will be remembered that in Blyth's process, although after the treatment with superphosphate of lime and sulphate of magnesia, "lime-water was then added, sufficient to precipitate the whole," yet this did not prevent "a third of the phosphoric acid added in the processes" from being left in solution and lost.

Possible loss of phosphate.

Whether this be the case or not with the present process, no hope is held out of profit from its employment apart from irrigation; "the profit, if any, will be but small, and not sufficient to encourage the belief that the ratepayers can altogether escape putting their hands into their pockets in order to cover the expense of disposing of their sewage" (p. 13).

We must, indeed, at once acquit Mr. Forbes of any belief that his process can be a substitute for irrigation where this is possible; he himself says:—

Not a substitute for irrigation.

There can be no question whatever but, that when the local circumstances of climate and soil are favourable to irrigation, and the conditions essential to its success properly observed, that sewage irrigation is the most natural and effective system for the utilisation of sewage, since it is only by this means that we can render available the whole of the ammoniacal salts upon which so very much of the fertilising value of sewage depends. (*Loc. cit.* p. 6.)

He believes, however, that by precipitating the offensive suspended matters with a mixture which enormously increases their value without adding useless ingredients, by completely deodorising them and the effluent sewage, while at the same time rendering this latter much richer in phosphates, this process will be found to obviate the objections at present raised against irrigation farming. May be combined with it.

This process, then, is not capable *alone* of utilising sewage, and there is little prospect of the effluent water from it coming up to the required standards of purity, as "it is not pretended that it attains any such high degree of purity as to admit of comparison, otherwise than in appearance, with the water supplied for the water-works, and it should be recollected that the object of the process is to purify sewage, not to manufacture drinking water out of it" (p. 10). Summary.

Whether it will answer to use it as a preliminary to irrigation, with the view of removing all offensive smell, and rendering both the deposit and the sewage more valuable, can only be determined by trial on some irrigation farm; the condition for success must be that all the valuable matter added be recovered and utilised, otherwise a loss would be entailed.

The British Association Committee conducted some experiments with the precipitating mixture used in *Whitthread's Patent Process* (Report 1872, pp. 142, 143). One pound of the mixture, stated to consist of dicalcic and mono-calcic phosphates, two equivalents of the former to one of the latter, was mixed with Whitthread's process.

100 gallons of Romford sewage, a little milk of lime being afterwards added.

The result was a very rapid precipitation, the supernatant water remaining nearly clear and quite inoffensive. The precipitate dried at 100° C. contained as much as 3 per cent of ammonia, and a considerable quantity of phosphate of lime. The supernatant water contained rather more actual ammonia than the original sewage, but scarcely any organic nitrogen, showing that the organic matters in solution, as well as those in suspension, had been almost entirely removed by the process. This water contained, however, a considerable quantity of phosphoric acid, which would be valuable if the water were afterwards used to irrigate land ; but, unless means are devised for separating it, it would constitute a serious loss if the water were thrown away.

Organic matters in solution and suspension almost entirely removed.

Although these results show a fairly efficient purification of the sewage, too much weight must not be attached to experimental trials of this nature, the conditions not being the same as if tried on the large scale requisite to purify the sewage of a town.

Only an experimental trial.

The process at Luton.

Whitthread's process was in 1874 in operation at Luton, Bedfordshire, for the purification of the sewage of the town. The process was reported on by the author (Professor Corfield) on the results of analyses made by Dr. Russell. It was found that nearly all the suspended matters of the sewage were removed, that the ammoniacal salts in solution were lost, that the organic matter in solution in the sewage (which was weak) was considerably reduced, so that the effluent was decidedly below the standard of purity required by the Rivers Pollution Commissioners, and that almost all the phosphoric acid added to the sewage was separated in the precipitate. The sludge, when dried at the boiling point of water, contained 45 per cent of organic and volatile matters, nitrogen equal to more than 2 per cent of ammonia (although some ammonia was, no doubt, lost in the drying process), and a considerable proportion of phosphoric acid,

Analyses of the effluent and precipitate.

chiefly, however, in the form of difficultly soluble phosphates. In conclusion the opinion was expressed that "the process may be relied upon for the purification of the sewage of Luton, so as to render the effluent water of sufficient purity to comply with the standard of the Rivers Pollution Commission, and it is the only precipitating process that I am acquainted with of which I could say this." As to the value of the manure, it was impossible to estimate it with any approach to accuracy.

Efficient purification of the sewage.

Bird's process, which has been carried on at Stroud and at Cheltenham, consists in the addition to the sewage of *crude sulphate of alumina*, which is prepared by treating pulverised clay with strong sulphuric acid; the mixture is allowed to settle in a depositing tank, and is filtered afterwards through coke. The coke is renewed about once in three weeks, and the foul coke is burnt. The sulphate for a day's use (150,000 to 200,000 gallons of sewage) is prepared by treating six cwts. of pulverised clay with 120 lbs. of sulphuric acid. The Rivers Pollution Commissioners' report with regard to Stroud, first, that the sewage was very weak, and next, that the effluent liquid, although much improved, was still not of the degree of purity which would render it admissible without nuisance into a clean river. Moreover, if stronger sewage were treated, the effluent water would doubtless be still more objectionable. We may add that at Cheltenham this process has been abandoned, the sewage being now utilised by irrigation on land (see p. 390).

Bird's process.

Effluent water much improved, but not purified.

The process has been abandoned.

Bird's process is still in use at Stroud, and was described by the late Dr. Voelcker to the Royal Commission on Metropolitan Sewage Discharge as being the cheapest process that can be used in localities where good clay, easily decomposed, or a clay that does not contain any lime, can be obtained. It is cheaper than lime because it goes further, but a good deal of clay is introduced into the deposit, so that the bulk of the sludge is sensibly increased, a very important matter for towns larger than Stroud.

Acid effluent.

It is to be noted, however, that this process leaves the effluent in an acid condition, and therefore not well suited for after utilisation on land.

Stothert's process.

Stothert's process consists in the addition of a mixture of "73½ grains of sulphate of alumina, 3½ grains of sulphate of zinc, and 73½ grains of moderately fine charcoal" to each gallon of sewage; and when this is well mixed with it, "22 grains of slaked lime, equal to 16¾ grains of quicklime, are added."

Precipitation of phosphoric acid.

The result differs from that of the lime process only in that the clarification is more complete; that the phosphoric acid is all precipitated, "in the form probably of phosphate of alumina;" and that the manure contains much more worthless matter derived from the precipitant. (*Second Report S. of T. C.*, p. 70.)

"A B C" process.

The "A B C" process (*Sillar's Patent*), which was carried on at Leamington and Hastings, and with which experiments on a large scale have been made at Tottenham and Leicester, consists in the addition to the sewage of a mixture containing *alum*, *blood*, *clay*, *charcoal*, some compound of *manganese*, and various other ingredients in smaller proportions. It will be seen that the only noticeable difference between it and some other processes already described consists in the addition of *freshly-drawn blood*, which is considered an essential feature in the mixture, and of a small quantity of various other ingredients. At Leamington (1867) this

"A B C" mixture is allowed to run into the sewer in a small stream as it enters the works, and causes the formation of a precipitate which settles to the bottom of the tanks in the form of a soft black mud. It is stated that this sediment may be used to precipitate a further quantity of sewage. It must then be removed from the tanks, which is done by pumping it up into large receptacles from which it is allowed to run into centrifugal drying machines. From these it is taken in a semi-solid state and spread out to dry on the ground near the works, being sprinkled from time to time with sulphuric acid in order to fix the ammonia which might escape during the drying. The effluent water, after standing for some time in another series of tanks, is allowed to run into the River Leam, and of it Dr. Letheby says, "*the water is practically defæcated*, and I should have no hesitation in saying that water is in a condition to run into a stream of comparatively large volume." The careful examinations, however, which have been made of the results of the application of this process, both at Leicester and Leamington, by the Rivers Pollution Commissioners (1868), have not confirmed this opinion. From the First Report of these Commissioners it appears that the solid matters in suspension are removed to about the same extent as by the lime process; that the dissolved impurities in the effluent water are markedly augmented; that the percentage of organic carbon removed "was notably in excess of that brought about by the lime process," while that of organic nitrogen (the most important substance, be it noted) was less than in the above-mentioned process, being only from 50 to 58·8 per cent. The amount of ammonia is, as in the case of the lime process, in-

Sediment.

Dried and sprinkled with sulphuric acid.

Favourable opinion.

Effect on sewage.

creased in the effluent water, the reason being that none of the ammonia originally present in the sewage is removed from it, while the additional amount is produced both from that contained in the alum of the mixture and from the action of the chemicals upon the nitrogenous organic matters both in suspension and solution in the sewage. The manure, however, from this process is perceptibly superior to that resulting from the lime process, but the increase in phosphoric acid in this manure is partly accounted for by the addition of an unknown quantity of bone-black to the precipitating mixture. In the Second Report of the above Commissioners the results of some further experiments on this process were recorded, and it appears that at Leicester the clarification was not satisfactory, suspended organic matter remaining to the extent of 1·5 to 3·8 parts in the 100,000; that with regard to the soluble constituents the results were the same as above given; as to the organic nitrogen, "it is precisely here that the process signally fails in accomplishing such an amount of purification as would render sewage admissible into an open water-course." (*Loc. cit.* p. 4.)

Manure.

Failure in removal of putrescible matter.

At Leamington the process was re-examined on the 10th May 1870, when the smell produced by the drying of the manure was exceedingly offensive, and "would be pronounced a nuisance whenever conducted in or near a town;" and, in fact, it had been protested against by some of the neighbours, who described it in the strongest terms as "intolerable," "pestilential," and "bringing, as we are apprehensive, disease and death to our very door." It had even been found necessary to use chloride of lime at the works. So much for the deodorisation.

Nuisance of process.

It was then found that the "A B C" liquid "was discharged into the sewage at the rate of about 210 gallons per hour;" and that it consisted of—

Exact composition of "A B C" mixture.

	cwts.	qrs.	lbs.
Ammonia alum	3	0	0
Clay (moist)	6	0	0
Animal charcoal	0	0	15
Vegetable charcoal	0	0	20
Epsom salts	0	0	20
Blood in a pailful of clay magma . .	0	0	4

and river water about 1135 gallons, as stated—analysis, however, indicating that only 1027 gallons had been used. (*Second Report R. P. C.*, 1868, p. 9.)

This mixture was contained in a tank which was exhausted in four hours and forty minutes. Small quantities of other substances are sometimes added.

Mr. Sillar pointed out to the Commissioners that the outlet for the water used in turning the water-wheel, which did the work of the engine during the night, was through the second set of subsidence tanks; it was not only so, but it was found that from leakage of the penstock and sluice, "even when the wheel was not working, a considerable stream of unpolluted water from the River Leam was mingling with the effluent sewage before it reached the place where our samples were taken." The result of this was shown in the analysis of the sewage after precipitation, but before filtration, as the amount of chlorine was found to be diminished from 11 to 9·5 parts in the 100,000, whilst the "A B C" mixture itself does not appreciably affect the proportion of chlorine. By a simple calculation based upon these considerations, it was found that with one part of sewage ·249 of river water was mixed, while the actual effluent water was found to contain river water varying from an inappre-

Leam water mixed with effluent sewage

Reduction of amount of chlorine.

ciable quantity to 416 parts for 100 of real effluent water. Another result of the admixture of this river water with the sewage was the occasional appearance of nitrates in the effluent liquid (pp. 7, 11).

Appearance of nitrates in the effluent water.

The Leamington sewage contains no nitrates, neither does the "A B C" process produce nitrates. On the other hand, 100,000 parts of water of the Leam contain ·178 part of nitrogen in the form of nitrates; consequently, if 416 parts of Leam water were mixed with 100 parts of Leamington sewage, the mixed liquid ought to contain ·143 part of nitrogen as nitrates. Our analysis shows ·149 part of nitrogen as nitrates, in 100,000 parts of the effluent liquid, a proportion which indicates a slightly larger admixture of Leam water than that deduced from the chlorine determinations. (*Loc. cit.* p. 12.)

The admixture with this large amount of river water of course causes the effluent water to be much purer than the process makes it. It is necessary, therefore, in estimating the alteration produced on the sewage by the mixture, to make a correction for the amount of river water that is thus mixed with the effluent water. This was done; and, further than this, an experiment was carefully tried to ascertain the effect of the "A B C" mixture on fresh London sewage, which "may be regarded as exhibiting the true amount of amelioration which can be obtained by this process, even with the employment of double the proportion of chemicals prescribed by the specification." The results of these experiments show—

Trial with London sewage.

Results.

1. That of the dissolved matters, those left on evaporation were increased in weight by nearly one-half the amount of soluble ingredients added to the sewage; for the "A B C" mixture making up 100,000 parts with the sewage to which it was added, contained, according to our analysis, 27·8 parts of soluble matters left on evaporation, whilst the increase of soluble matters left on evaporation shown in the above table amounts to 13·2 parts.

2. That the organic carbon in the dissolved matters was diminished to the extent of 37·5 per cent.

3. That the organic nitrogen in the dissolved matters underwent no alteration; consequently, the organic matters precipitated from

solution by the "A B C" mixture were non-nitrogenous, and therefore valueless as manure.

4. That the proportion of ammonia was augmented, because more was added in the "A B C" mixture than was precipitated by the action of that mixture upon the sewage. 100,000 parts of the "A B C" mixture gave on analysis 132·1 parts of ammonia; there was consequently added to each 100,000 parts of sewage in the "A B C" mixture, 1·32 part of ammonia, whilst the augmentation of ammonia shown in the above table is ·668 part.

5. That no nitrates were formed in the operation.

6. That the total combined nitrogen was augmented by the ammonia added in the "A B C" mixture; consequently, as regards soluble constituents, the effluent liquid possessed a greater manure value than the raw sewage, the increase in value being due to the ammonia in the chemicals employed.

7. That the proportion of chlorine remained unaltered.

8. That the matters in suspension, both mineral and organic, were almost completely removed, although the defecated sewage remained perceptibly turbid (p. 13).

"On no occasion, even when mixed with more than four times its volume of clean river water, was the effluent sewage other than a polluting liquid, offensive to the senses even at the moment of discharge, and always quite unfit to be admitted into running water." That this is really the case is seen from the fact that the water of the Leam was considerably polluted below the outfall of the sewage works.

Effluent water offensive

Masses of putrid mud, like those we had observed in the filter tanks, were floating here and there on the surface, buoyed up by the gases generated during putrescence. . . . Sewer fungus * was growing abundantly on submerged objects near the banks, and we observed that it markedly increased in quantity as we approached the works on our return up the river (p. 14).

River polluted.

In fact, it is shown by analysis that the organic nitrogen contained in the river water was increased from ·061 to ·102, the ammonia from ·040 to ·370, and the "total combined nitrogen" from ·272 to ·586, part per 100,000 after receiving the effluent water.

As to the manure produced by this process, it will

* See p. 437.

be anticipated, from what has already been said, that it cannot be valuable. The analysis of some mud from one of the subsidence tanks showed it to contain 2·05 per cent of total nitrogen calculated as ammonia, and 1·98 per cent of phosphoric acid. Of this manure Messrs. Lawes and Gilbert say —

Composition of mud manure.

> Assuming such a manure to be produced in large quantities, our opinion is that it would certainly be worth more per ton than stable-dung, provided the nitrogenous substance were in an easily decomposable condition, and its nitrogen readily available, and provided the phosphoric acid were also in a readily soluble condition; but if the nitrogen and phosphoric acid were not in such conditions, it may be a question whether the "A B C" deposited manure or stable-dung would be the most valuable. The result would depend in a measure on the quantity of the respective manures in the market, the cost of carriage, and other local circumstances. Stable-dung would, however, probably have the preference for market gardening. (*Second Report*, *R. P. C.*, Appendix, p. 31.)

Estimation of its value.

From calculations based upon the market price of guano and bone super-phosphate, the Commissioners find that the "A B C" manure appears to be worth about 32s. per ton.

Comparison with guano and super-phosphate.

> That is to say, 160 cwt. of the "A B C" manure would be worth as much as 20 cwt. of guano, or 55 cwt. of the super-phosphate, supposing both to have been deposited upon and within the soil. It is plain, however, that this supposition cannot be realised without a much larger expenditure on the weaker manure, for carriage and labour of distribution, than in the case of guano or of super-phosphate; an expenditure which indeed very soon altogether destroys the commercial value of the manure, as it diminishes in strength (p. 16).

But several considerations show that this price is really too high. Dr. Odling, from the examination of the prepared manure, states that "it contains about one twenty-fourth part of the nitrogen which is contained in guano, and less than one twenty-fourth part of the amount of phosphate; so that, estimating it merely as regards those two constituents, it would have been one twenty-fourth part of the value of

Value 1-24th that of guano.

guano—making no deduction for the amount of dilution." That is to say, he estimates its value at 11s. 3d. per ton. But it is plain that the value of this, or any other manure, may be raised to any amount by the addition of suitable ingredients, and it appears that "an artificial fortification of the comparatively worthless sewage mud thrown down by the "A B C" mixture is occasionally practised." Drs. W. A. Miller, F.R.S. and W. Odling, F.R.S., found that many samples of the manure "contained large crystals of sulphate of ammonia," which, it was stated by the manager, had been added by mistake for sulphate of magnesia. It must be remembered, too, that animal charcoal, blood, and salts of potash, beside some ammonia-alum, are all contained in the precipitating mixture. The manure produced (1870) fetches £3 : 10s. a ton. When we consider that the lime mud from the Leicester Sewage Works fetches only 1s. a ton, although the theoretical value of it is 15s. 5d., according to Voelcker's analysis, we may be certain "that the theoretical value of the Leamington 'A B C' manure will not be nearly realised when its price shall have been determined by the ordinary process of competition with other purchasable fertilisers." Much less will any such extreme price as that being given for it be realised. On the whole it appears that the manure value of the chemicals used in the "A B C" mixture for one day's working is 11s. 7d.; taking the highest theoretical value given for the manure—about £1 : 14 : 9—it appears that the "nett result of a day's working was the recovery from the sewage of Leamington of manure constituents worth theoretically £1 : 3 : 2." It would appear, then, "the 20,000 inhabitants of Leamington would yield annually, by

Fortified by addition of sulphate of ammonia.

Price it fetches.

Highest theoretical value.

the 'A B C' process, manure of the theoretical value of £845 : 11 : 8 or 10d. per head per annum." "The actual value of the recovered manure would, at 7s. a ton (about its probable practical value), amount to £255 : 10s., or 3½d. per head per annum." Even if it fetched the theoretical value given above, it would not pay the cost of working (pp. 17, 18).

Comparison with Lancashire middens.

This is an even less satisfactory result than is obtained by ordinary scavenging operations in the Lancashire towns, where manure of the annual value of rather less than 5d. per head over a population of more than a million is annually obtained.

The conclusions, then, of the Royal Commissioners are on every point condemnatory of the "A B C" process.

The manager of the Company maintains (letter to the Clerk to the Metropolitan Board of Works) that the conclusions of the Commissioners are unwarranted, especially as regards the admixture of river water with the effluent water, as would have been shown by gauging the effluent water, or by comparing its temperature with that of the sewage; that the "fortification" alluded to took place on that occasion only, and was done without the knowledge of himself or of the Directors; and that the manure produced is proved to be valuable by the avidity with which it is bought up by farmers and others.

General results of personal inspection.

On a visit that we paid to the works at Leamington on 21st July 1870, we were agreeably surprised to find that, on that day at any rate, the amount of nuisance caused by them was very little indeed throughout the whole of the premises. We could not find any disagreeable smell with the single exception of the air in the subsidence tanks; that was decidedly foul, and moreover issued in a strong current when the trap-door in the roof of one of the tanks was opened. Some experiments in tall precipitating glasses showed that sewage was *clarified* considerably by the "A B C" mixture; but that the supernatant liquid contained a great deal of ammonia. As to the effluent water, it was turbid and had a slight odour and colour. We found it, on a rough and ready examination, to contain a very considerable quantity of ammonia, and on pointing out this fact to the manager he acknowledged that all the ammonia that came to them in the sewage they must inevitably lose, but stated that they got the sewage so fresh that it really contained very little ammonia. It is perfectly certain that this can never be the case, and in fact the analysis of the sewage shows that it contains about from 3 to 10 parts in 100,000: the ordinary quantity being 7 or 8 parts. The sample of the effluent water, which we preserved, became excessively foul in a day or two, although kept in a stoppered bottle, and disengaged a quantity of sulphuretted hydrogen gas. It was found by Dr. Russell to contain 2·856 parts of ammonia and 0·080 part of "albuminoid ammonia" in 100,000. As to the river itself, we noticed that near the outfall, especially just about and underneath the weir, the surface of the water was covered with a filthy scum. We could only obtain evidence, with regard to the agricultural value of the manure, from some florists who appeared very well contented with it; but it need hardly be pointed out that with potted plants and so forth a proportion of manure is used which would come to an enormous quantity if calculated per acre, and that no value could be given to estimates produced in this manner. A process which does not even pretend to remove the manurial constituents

Ammonia acknowleged to be inevitably lost.

Effluent water putrefies.

Agricultural value of the manure.

from the sewage cannot possibly produce valuable manure; and Dr. Odling says:—

Summary of results.

No doubt this method, like all other methods of precipitation, does keep out a considerable proportion of filth from the river; but there was a great deal of putrescible matter in the effluent liquid, and in comparing this mode of precipitation with others, it did not seem to me that its alleged superiority had any foundation.

As regards its superior defecation of sewage, and the high value of the product yielded, I came to the conclusion that it was simply a juggle.

From the Report of the Committee of the Local Government Board on Modes of Treating Town Sewage, we find (Appendix, p. 20)—

Offensive smell caused by drying the sludge.

The extraction of the sludge and drying it, especially in hot weather, in order to convert it into a manure, was attended with a nauseous odour, and caused an intolerable nuisance and extreme annoyance to the residents of Milverton, a populous and fashionable suburb of Leamington, who made repeated complaints to the Local Board of the suffering they endured day and night from the offensive smell caused by the method adopted by the company for drying of the sewage mud.

The process of the "A B C" Company was discontinued at Leamington in October 1871, in favour of land irrigation.

The "A B C" process has been also tried at Leeds, Bolton, and Crossness.

"A B C" process at Crossness.

At Crossness the process was carried on experimentally in 1871-72, and the effluent water was reported by the chemist to the Metropolitan Board to be "on the whole, very good," and "in a fit state to be admitted into any ordinary river, without producing a dangerous degree of pollution." But during the whole time of the experiment, owing to long continued rain, the sewage at the southern outfall (Crossness) was abnormally weak and deficient in putrefactive matter, so that the results of the experiment were regarded as somewhat inconclusive.

At Leeds the "A B C" Company failed to carry out the contract they entered into with the Corporation in 1870, to purify the sewage of Leeds before the works which were being built for them by the Corporation were completed. They alleged as a reason for desiring to be released from the penalties of their contract that they could not sell the manure they had already manufactured, and they offered to allow the Corporation to use all their patents, without paying a royalty. The Corporation subsequently carried on the process themselves for one year (1875), at a cost of £15,000, exclusive of the cost of drying the deposit, and converting it into a manure. It was then discontinued. (*Report of Committee of the Local Government Board*, 1876, Appendix, p. 50.) "A B C" process at Leeds.

At Bolton, where, in the opinion of Mr. Sillar, "the conditions were especially favourable for the experiment, on account of the quality, abundance, and cheapness of the ingredients required" (Birmingham Sewage Inquiry Report, 1871, p. 50), the "A B C" process was carried on from 1870 to 1873, and was then abandoned, owing to the great expense of working it, and also because the manure manufactured from the sludge could not be sold. (*Report of Committee of the Local Government Board*, 1876, Appendix, p. 37.) "A B C" process at Bolton.

The "A B C" process is now carried on by the Native Guano Company at Aylesbury, and was described by Mr. Sillar to the Royal Commissioners on Metropolitan Sewage Discharge (*Second Report*, p. 50). There is first added to the sewage stream a mixture of substances, consisting principally of charcoal, blood, and clay, which is said to have a preliminary effect of "A B C" process carried on at Aylesbury by the Native Guano Company.

"deodorising or purifying the sewage," after which there is added a salt of alumina, which "causes a rapid and copious precipitate." The "chief purifying element" is considered to be the clay, to which the blood is also an auxiliary. No lime is used by the Company, as they consider that it deteriorates both the effluent and the precipitate.

Sale of the precipitate.

The Company declared to the Commissioners that the whole of the precipitate they make at Aylesbury has a ready sale at £3 : 10s. per ton (*Second Report*, p. 36). As it requires 880 tons of sewage to produce a ton of the precipitate, the sale of the precipitate gives about 1d. per ton as the value of the sewage. The cost of the production is said to be equal to the sale, so that even with this high return, there is the loss of interest on the cost of the works. The Commissioners here remark: "There is something unintelligible about this case. If 2s. is the value of the suspended matters in 100 tons of sewage, the value of the suspended matters in 880 tons should be a trifle over 17s. We are at a loss to see how it can fairly sell for £3 : 10s., and, as we have said, the Company cannot explain the difficulty."

"Something unintelligible about this case."

Remarks.

Looking at the past history of the "A B C" process, and its uniform inability to make a profit out of its manure, it is certainly somewhat strange that the Native Guano Company, employing practically the same process, can produce a manure which is worth four times as much as the theoretical value of the constituents of the sewage sludge from which it is made, especially as Dr. Voelcker has shown that artificial manures are practically worth only from one-third to one-half of their theoretical value: and this value will hardly be accounted for by the quantity of phosphates and nitrogenous matters introduced with the blood, —one of the ingredients of the precipitating mixture, —as the amount of blood by weight added to the sewage is insignificant.

Mr. Sillar's explanation.

Perhaps Mr. Sillar's explanation to the Royal Commission of the high value of the manure may be interesting. When asked to what he attributed its higher value agriculturally than could be deduced from its chemical composition, he replied that he attributed it to the fact "that it is the natural substance which was intended to manure the earth, and that the earth has a natural liking for it independently of its actual ammonia or phosphate strength,"—a truly remarkable answer!

The fact that a Royal Commission has issued a Special Report on the above process, and that the manure is being sold at so high a price, must be our excuse for describing it at a greater length than the others.

Anderson's process.

Dr. Anderson's process has been tried at Coventry. The General Sewage and Manure Company having acquired this and other patents contracted, in 1872, to purify the sewage of Coventry, estimated at two million gallons daily. Their process was investigated by the Committee of the Local Government Board on Modes of Treating Town Sewage, 1876 (Appendix to Report, p. 47). The sewage, which is weak, owing to the large volume of subsoil water mixing with it in the sewers, is passed through extractors to remove the coarser suspended matters, and then flows into circular mixing tanks, where it is thoroughly mixed by means of agitators driven by steam power, with a mixture of a saturated solution of crude sulphate of alumina, heated to the boiling point. The crude sulphate is prepared from ordinary clay, or from the shale of the coal measures by treating with concentrated sulphuric acid. The sewage after mixing flows into another series of tanks, where it is mixed with milk of lime and agitated by machinery. From the liming tanks the defecated sewage flows into subsidence tanks, and thence along a conduit which discharges it on to an area of 4½ acres of loamy soil, which has been roughly laid out as a land filter, and drained about 5 feet deep with an outlet into the river Sherborne. At the time of the visit by the Committee, the effluent water was clear and inodorous. The sludge is dried by artificial heat, by sewage mud-drying machines. There is a difficulty in getting rid of the sludge, as also of selling the manure (the dried sludge). The sludge has been sold at 3s. per ton, the cost of production being 4s. 10d. per ton. The cost of drying the sludge to produce the manure is £1 : 9s. per ton in addition. The Committee remark that "these works have from the first been carried on at a loss of not less than £1500 per annum for each million gallons of sewage per day treated ; and apparently this rate of loss must continue so long as this mode of treatment is continued."

Effluent is filtered through land.

Difficulty in selling the sludge.

The quality of the effluent water from the precipitating tanks is shown by the fact that it has to be further purified by filtration through land before it can be admitted into the river Sherborne.

At Coventry, at Hertford, and at Leyton in Essex, the sewage is now precipitated by lime and sulphate of alumina, with or without protosulphate of iron. At Coventry about a ton of sulphate of alumina, costing £3 per ton, is daily mixed with the sewage, which averages 2 million gallons per day. Then lime in

The Coventry process.

about the same quantity is mixed with the sewage in liming tanks, but the use of protosulphate of iron has been discontinued. After settling in the tanks the effluent is run on to about 8 acres of land, laid out as a filter bed. The sludge is compressed in Johnson's filter presses, and contains after this process about 55 per cent of moisture. The effluent from the filter presses is, although clear, saturated with sewage matters, and undergoes the same treatment as the sewage in the tanks. The larger solid matters in the sewage are removed as the sewage reaches the works by a Latham's extractor, a revolving wheel with sifter vanes, which deposits them in a small tank for subsequent removal. It is intended to increase the size of the settling tanks, which are at present too small. With these improvements, and with the aid of land filtration properly carried out, the sewage should be efficiently purified. The area of land, 8 acres, at present used is very much too small for a town of 45,000 inhabitants, such as Coventry is.

Sludge compressed.

Johnson's filter press consists of a number of grooved discs arranged in series, each disc having a central perforation, and being separated from the disc on each side by a filtering cloth. The liquid sludge is forced into and between the discs by compressed air at a pressure of 100 to 120 lbs. per square inch, the liquid, being forced through the filter cloths and along the grooves on the discs, escapes, whilst the solid portions remain behind in the centre of the discs, to be subsequently removed as a more or less solid cake.

Johnson's filter press.

That the process which is carried out at Hertford and Leyton is not capable of procuring a pure effluent is shown by the evidence of Major Flower, Engineer to the Lea Conservancy Board, given before the Royal

Process at Hertford and Leyton.

Evidence of Major Flower.

Commission on Metropolitan Sewage Discharge (Minutes of Evidence, vol. ii. p. 103). He describes the effluent from the Leyton sewage works as undergoing secondary decomposition, and becoming offensive after discharge into the Lea, and bringing about a "very filthy condition of things." He finds also the same thing at Hertford.

Scheme of the Lower Thames Valley Board.

A process of precipitation by lime, iron, and sulphate of alumina was adopted by the Lower Thames Valley Main Sewerage Board, and having received the sanction of the Local Government Board, would have been applied to the sewage of the towns in the Lower Thames Valley at Mortlake, had the scheme not been rejected by a Committee of the House of Commons in 1884. By this process the sewage was first to be screened to remove the grosser matters, and then to be treated with milk of lime, and after an interval of a few minutes with crude sulphate of alumina and protosulphate of iron in solution. It was anticipated that all the chemicals used would be deposited in the sludge, with the exception of a trace of sulphate of lime, which, being slightly soluble, might find its way into the effluent, and that the latter would be deprived of all sewage odour.

Lime, alumina, and iron process.

Experiments by Mr. Dibdin and Dr. Dupré.

From the experiments on treating London sewage with chemicals, carried on by Mr. W. Dibdin, chemist to the Metropolitan Board of Works, in conjunction with Dr. Dupré, it appears that only 5 per cent of the dissolved organic matter of the sewage, as determined by the albuminoid ammonia process and by the oxygen absorbed, was removed when alum was used as a precipitant, but none at all when iron and lime were used. Lime in solution in water, in the proportion of 4 grains to the gallon, they found to be the best material to remove the suspended matters. This amount of lime, with protosulphate of iron in the proportion of 1 grain to the gallon, was sufficient to precipitate the whole of the suspended matters, and also to remove the "grosser sewage odour." The addition of sulphate of alumina as a precipitating agent considerably increases the bulk of the sludge, chiefly owing to the fact that alumina carries down a good deal of water with it. The sludge produced by protosulphate of iron is said to be denser, and precipitation by iron and lime to be more rapid than by any other process, but the sludge produced when alum is used is more easily pressed into cakes than when lime, 5 grains to the gallon, and iron, 1 grain to the gallon, alone are used.

Evidence of Mr. Dibdin.

In his evidence before the Royal Commission on Metropolitan Sewage Discharge (vol. ii. p. 114), Mr. Dibdin stated that the addition of sulphate of alumina to the other precipitants, lime and protosulphate of iron, had the effect of producing a better effluent than when the two latter were used alone, but that the difference could not be detected by sight or smell, but only by chemical analysis. This result is no doubt owing to the effect of alum in precipitating a small percentage of the dissolved organic matter. Mr. Dibdin estimated the cost of the alumina, lime, and iron process, taking 5 grains of alumina sulphate to the gallon as the proportion, as being four times more costly than when lime and iron are used alone. The cost of lime is about £1, of protosulphate of iron £2, and of sulphate of alumina £3 per ton. Five grains of lime to the gallon as lime water, *i.e.* lime dissolved in water, was found to be as effective as 15 grains to the gallon of milk of lime in precipitating the sus-

Lime water instead of milk of lime.

pended matters, but the larger quantity of lime in the latter case renders the sludge produced easier to press. In the course of the experiments it was found that sometimes, especially on Saturdays, lime would not precipitate the sewage completely, a heavy scum rising to the surface, which was carried down again on adding a little iron. This result was attributed to the unusually large amount of soap used on Saturdays for washing purposes.

Evidence of Dr. Voelcker.

The late Dr. Voelcker, in his evidence before the Royal Commission on Metropolitan Sewage Discharge (p. 76), considered that the best method of dealing with the London sewage would be to precipitate it with sulphate of alumina, 6 or 7 grains to the gallon, and lime about half that quantity, to ensure a perfect neutrality or slight alkalinity, so as to make the whole of the alumina come down. He considered that not more than 9 grains of chemicals to the gallon should be used.

Lime useful where the sewage is acid.

In the case of many manufacturing towns the sewage contains free acids, acid-salts, and metals in solution, and the use of lime to precipitate these matters and render the sewage neutral is a necessary condition precedent to any attempt to purify the sewage on land, and to utilise it by the growth of crops. Thus at Birmingham, where the sewage contains immense quantities of "pickling liquor," 15 grains of lime to the gallon must be added before the effluent can be used on the land. The opinion often expressed that lime deteriorates the manurial value of an effluent by causing an evolution of ammonia is erroneous; but, on the other hand, the sludge and effluent produced by lime tend soon to undergo further fermentation and decomposition, unlike the sludge and effluent pro-

Sludge produced by lime decomposes.

duced by sulphate of alumina. This tendency to decomposition is not, however, exhibited, if the proportion of lime added is insufficient to cause a marked alkalinity in the sewage, but it is not easy to ensure that an excess of lime will not be added. One of the beneficial results of the addition of sulphate of alumina is the neutralisation of any excess of lime which may be present. Dr. Thomas Stevenson is of opinion that the slaked lime added to sewage should not exceed the hardness of the water-supply, *i.e.* if one grain of lime per gallon be added for each one degree of hardness of water-supply, no appreciable excess of free lime will remain in the effluent. (Paper on "Sewage Disposal," read before the Society of Medical Officers of Health, 1884-85.)

Precipitation by lime and alumina.

The precipitating effect of lime on sewage is partly due to its combination with free and partially combined carbonic acid, and partly to combination with some of the organic matters of the sewage, whilst the precipitation effected by sulphate of alumina is due to its combination with lime or carbonate of lime in the sewage to form sulphate of lime, whilst the alumina hydrate is precipitated in a flocculent state, entangling and carrying down much of the suspended organic matters, whilst some of the soluble organic matters are also thrown down.

Dr. Stevenson expresses the opinion in his paper just quoted, that

Protosulphate of iron as a precipitant.

"The addition of a small quantity of green vitriol (protosulphate of iron) to the sewage as an additional precipitant to lime, is highly beneficial; this substance fulfilling a useful and important function not fulfilled by the substitution of any other chemical for a protosalt of iron. The lime secures the precipitation of a highly flocculent hydrated protoxide of iron, which acts as a carrier of oxygen, absorbing free oxygen and again giving it up to organic matters, just as the red blood pigment absorbs oxygen to again give it up to the effete tissues.

When the iron salt is used, a small quantity of a soluble protosalt of iron remains in solution in the effluent, and acts as a very efficient carrier of oxygen. But the use of protosulphate of iron is attended with blackening of the mud-banks in the stream into which the effluent sewage is discharged, and although this is a mere sentimental disadvantage,—or rather in reality an advantage, it cannot be altogether lost sight of. The blackening is due to the formation of sulphide of iron, by which the unoxidised sulphur of sewage is fixed, and deodorisation effected."

Mud-banks blackened.

Dr. Stevenson thinks, however, that the iron salt should be omitted if the effluent is subsequently to be treated on land.

In his evidence before the Royal Commission on Metropolitan Sewage Discharge (Minutes of Evidence, vol. ii. p. 142), Mr. Dibdin stated that it is possible to thoroughly deodorise the sewage by means of manganate of soda and sulphuric acid, either before or after the treatment for the precipitation of the suspended matters, but he only proposed this as a supplementary measure to prevent any nuisance arising from the establishment of precipitating works on the sites of the present outfalls. This process is one of oxidation, and would be found, Mr. Dibdin asserted, to remove from the effluent the faint sewage odour which is left after the addition of lime and iron or other precipitants to the sewage.

Deodorisation by manganate of soda.

By the lime and iron process Mr. Dibdin estimated that 2600 tons of wet sludge, containing about 95 per cent of moisture, would be produced daily from the metropolitan sewage. This amount would be reduced to about 500 tons by pressing in one of Johnson's filter presses, and would then contain from 55 to 60 per cent of moisture, half the residue being mineral and half organic matter. The cakes so obtained, he stated to the Commission, could be burnt in a Hoffman's furnace, where they would serve as

Burning the sludge.

their own fuel, whilst the process could be conducted without the slightest nuisance. About 150 tons a day of ash would be produced, which might be utilised for the purpose of lightening clay land, or of filling up waste ground, or might be made into cement.

At Ealing, the sludge, which is produced from the sewage by treatment with 11·5 grains of clay and 10 grains of lime per gallon, a little iron and alumina being also used, after losing about 25 per cent of moisture by draining, is mixed with about two-thirds its volume of ashes and house refuse and burnt in a Destructor furnace. Sludge burnt at Ealing.

At Southampton, there is added to the sewage, before its arrival at the depositing tanks, an artificial product made from Devonshire lignite, called "porous carbon." The sludge produced by this process is somewhat carbonaceous, and is mixed with road scrapings to form a manure selling at 2s. 6d. a load; or should there be no demand for the manure, it is mixed with dustbin refuse and burnt in a Destructor. Sludge produced by "porous carbon;" sold as manure, or burnt.

As a preliminary to purifying sewage on land by intermittent downward filtration, a precipitating process—the simplest and least costly being the best—is of great value. The suspended matters and, with them, the slimy matters, are removed, which, if raw sewage is run upon land, soon tend to clog its pores, and form a coating impenetrable to air and therefore to oxygen: at the same time most of the bacterial organisms and their spores, the agents in putrefaction, are carried down in the precipitate and removed from the effluent, which is consequently less prone to putrefy and readier to undergo nitrification in the soil—putrefaction and nitrification being antagonistic processes. The slimy Precipitation removes putrefying organisms.

matters in sewage alluded to above are derived from the grease of the kitchen waste waters, the fats of soap, and the mucus from the urinary and intestinal mucous membranes, and also no doubt from macerated paper, as pointed out by Mr. Rogers Field.

In the Report of a Committee of the Local Government Board on Modes of Treating Town Sewage (1876, pp. 60-63) is contained a very valuable Report by the late Dr. Voelcker, F.R.S., on the "Fertilising and Commercial Value of Sewage and Night-soil Manures."

Calculation of the theoretical value of manures.

Dr. Voelcker calculated the theoretical or estimated money value of manures from the quantities of the following constituents in each, namely :—

Insoluble phosphate of lime at 1d. per lb., soluble phosphate of lime at 2d. per lb., potash at 2d. per lb., nitrogen calculated as ammonia at 8d. per lb ;

these being the rates at which these fertilising constituents of manures may be bought in the form of concentrated artificial manures, such as guano, bone-dust, sulphate of ammonia, etc.

The practical or market value.

The practical or market value he calculated at from one-third to one-half the theoretical value ; the difference representing the greater expense in carriage and application to land of the more bulky and weaker manure, and the less efficacy and value of nitrogen in the form of nitrogenous organic matter, than in the form of ready-made ammonia.

Sewage manures.

Sewage manures contain a large proportion of matters, which occur in abundance in almost all soils, and which, therefore, having no commercial value, detract from the price by the cost of their carriage and application to land; and Dr. Voelcker believes that by far the largest proportion of nitrogen in these manures occurs in them in the shape of nitrogenous organic matters, the amount of ready-formed ammonia contained in them being but small.

"According to the most reliable statements the separation of the suspended matters of sewage by precipitation and filtration, and the production of one ton of dried sewage deposits, apart from the costs of the precipitation agents which are used, entails an expense of about 30s. for each ton of portable dried sewage manure." Cost of production of dried sewage manure.

It will be seen from Dr. Voelcker's table of values, that the cost of manufacture of every one of the manures there given considerably exceeds its theoretical or estimated money value. Dr. Voelcker calculates the theoretical value of a ton of good farmyard manure to be about 15s., but he says :—

Good dung can be bought in many places at 5s. per ton, or one-third its estimated money value, and, practically, the highest price which a farmer can afford to pay for good dung, if he has to cart it even a few miles, would not exceed 7s. 6d. per ton, one half its estimated money value. Farmyard manure.

Value of one Ton of the treated Sewage Sludge.	Theoretical or Estimated money value.			Practical or Market value.				
	£	s.	d.	s.	d.		s.	d.
1. Bolton sludge from the "M and C" sewage process	0	9	8½	3	3	to	4	10
2. The same dried, leaving 15 per cent of moisture in the sludge	1	1	1	7	0	,,	10	6
3. Solids drained from sewage before the liming process at Bradford	0	11	0½	3	8	,,	5	6
4. The same with 15 per cent of moisture	0	19	3	6	5	,,	9	6
5. Bradford Corporation sewage outfall works sludge from drying pits, no artificial heat being used	0	4	8	1	6	,,	2	4
6. The same with 15 per cent of moisture	1	0	0½	6	8	,,	10	0
7. Deposit from the sewage of Leeds treated by the "A B C" process	0	8	4½	2	9	,,	4	2
8. The same with 15 per cent of moisture	0	16	8½	5	6	,,	8	4
9. Manure produced by the General Sewage Manure Company at Coventry	0	16	9½	5	6	,,	8	4
10. Rochdale Manure	0	15	11½	5	4	,,	8	0
11. Manure manufactured by the Goux Company at Halifax	0	17	7	5	10	,,	8	9

Dr. Voelcker concludes his Report with the following words :—"Indeed comparatively few farmers are so Dr Voelcker's conclusion.

situated that they can afford the expense of carting semi-dried sewage sludge, containing from 60 to 70 per cent of moisture, from the works to their fields. The refusal to accept such sludge as a gift, in not a few instances, rather shows sound discrimination than ignorance on the part of the farmers."

Precipitation processes abroad.

From a paper on "The Drainage of Continental Towns," by Mr. J. Gordon (Transactions of the Sanitary Institute of Great Britain, vol. vii.), it appears that Frankfort, Wiesbaden, and Dortmund have adopted chemical precipitation as a means of purifying their sewage; but at Dortmund the sewage is precipitated merely as a preliminary to irrigation. The rivers on which these continental towns are situate being so much larger, and the populations on their banks so much smaller and more scattered than in the case of English towns, Mr. Gordon is of opinion that a simple method of partial purification of the sewage, such as the lime process, is sufficient for those towns, in which the sewage effluent becomes at once very largely diluted by a large volume of fresh flowing water.

Applicability of precipitating processes to the Metropolitan sewage.

The Royal Commissioners on the Metropolitan Sewage Discharge express the following opinion as to the applicability of precipitating processes to the case of the Metropolitan sewage at the present outfalls (*Second Report*, p. 58) :—

1. That the adoption of a process of this kind would effect an improvement on the present state of things. It would diminish the nuisance, and it would lessen the tendency to deposit foul banks and shoals.

2. But that precipitation alone would not effectually purify the river; some nuisance would probably still occur in dry seasons; and the injury to fish and danger to wells would in some degree still exist.

3. That the works might be carried on without sensible nuisance.

4. That the cost would be at least £200,000 a year, or about 1s. per head of the population.

5. That it would result in the loss, practically, of a large part of the manurial value of the sewage, offering no prospect of its future realisation, unless the clarified liquid was afterwards applied to land.

6. That several processes appear to be fairly effective, but that there has been no evidence to satisfy us of the marked superiority of any one in particular.

The Committee of the British Association on the Treatment and Utilisation of Sewage arrived at the following conclusions (*Report* 1873, p. 449):—

That the precipitation processes that it (the Committee) has examined are all incompetent, and necessarily so, to effect more than a separation of a small part of the valuable ingredients of sewage, and that only a partial purification is effected by them. Some of them may, however, be useful as methods of effecting a more rapid and complete separation of the sewage sludge.

Precipitating processes effect only a partial purification.

Conclusions.

All these precipitation processes do, then, *to a certain extent*, purify the sewage and prevent the pollution of rivers, chiefly by removing the suspended matters from the sewage; but they all leave a very large amount of putrescible matter in the effluent water, and at least all the ammonia contained in the sewage (sometimes they add to it); the greater part of the phosphoric acid is precipitated by some of them, while they increase the hardness of the river water, a matter of great importance if the stream be a small one.

Ammonia not precipitated.

The manures that they produce are in every case very inferior, as may be expected from the known value of the sewage constituents that can be precipitated. They have all failed in producing valuable manure, because the valuable constituent of sewage *par excellence* is the ammonia, which of course invariably escapes in the effluent water, and is lost to the manure: this shows the futility of all attempts to utilise sewage by precipitation alone.

CHAPTER X

FILTRATION

Several processes for filtering sewage through ashes or charcoal have been tried, but they have not been found to produce a good effluent, and the manure obtained has not always found a sale.

At Bradford in 1871 the town sewage was leased to the Peat Engineering and Sewage Filtration Company, to be purified by filtration through peat charcoal. But the process failed, because the sediment choked the filters; and as the filtering medium required to be constantly replaced, the cost was ruinous. The process was consequently abandoned. The Corporation of Bradford then attempted to purify their sewage by a combined process of precipitation and filtration. Milk of lime was mixed with the sewage in large subsidence tanks, and the effluent, after passing through coke filters, was allowed to flow into the Bradford Beck. One ton of lime was used for every million gallons of sewage. The sludge produced was difficult to dry and commanded no sale. (*Report of the Committee of the Local Government Board*, Appendix, pp. 42-45.)

Filtration through peat charcoal.

A method for the purification of sewage, described as the "Carbon Filtration Process," has been patented by Messrs. Weare & Co., of Newcastle-under-Lyme. It consists essentially in the filtration (intermittent as far as may be) of the sewage through several tanks containing town ashes and vegetable charcoal.

Filtration through town ashes and vegetable charcoal.

The system is in operation (1871) at the Stoke-upon-Trent Workhouse, where the tanks are entirely underground, and the process is carried on without being perceived at all by the passers-by. The large tank into which the sewage is received directly from the workhouse is double, so that one half can be used while the other is being emptied; in this tank most of the suspended matters are retained, while the fluids pass through a perforated dam and a filter of coarse ashes, and are conveyed by a pipe to a series of three smaller tanks, containing vegetable charcoal and fine ash; passing through these in succession, the water is still further purified, and then allowed to escape into a drain.

The process was examined at the Stoke-upon-Trent Workhouse by the Birmingham Sewage Inquiry Committee (*Report*, 1871, pp. 51-57). The manure, which consists of the used filtering materials and the suspended matters of the sewage, when mixed with soot to dry it, and watered with sulphuric acid and ammonia to bring it up to standard strength, is stated to realise £4 per ton. Without the soot and ammonia, its value is £2 per ton. No offensive odour was perceived by the Committee either in the manure manufactory or in the tanks. About 50 tons of charcoal and 50 tons of cinders are required yearly for the 700 inmates of the workhouse, with a daily flow of sewage of 10,000 gallons. The estimated yield of manure is about 250 tons. The effluent contained no suspended matters, but some organic matters in solution, and a much larger quantity of ammonia and mineral salts than the raw sewage. The analyses indicate that "although the system may be effective,

Value of the manure.

Quality of the effluent.

at any rate on a small scale, for the separation of suspended matters, yet that it is possible, when the filtering medium is not renewed with sufficient frequency, for the effluent water to pass away with even more valuable elements than the raw sewage itself possessed, and this possibility is sufficient to create some doubt as to the intrinsic value of the resulting manure, since charcoal, although it may be usefully employed to mix with and lighten stiff soils, is not in itself a fertiliser. The analysis also suggests the use of the process to arrest suspended matters in sewage previous to irrigation."

Effluent more valuable than raw sewage.

The Committee of the British Association found that Weare's charcoal filtration process, as carried on at the Stoke-upon-Trent Workhouse, did not give very satisfactory results. For although the suspended matters were removed, and the ammonia and organic nitrogen much reduced in quantity, no oxidation took place, as no nitrates were found in the effluent water, "which was to all intents and purposes a dilute sewage, and 'had a strong smell of sewage.'" (*Report*, 1872, p. 138.)

Effluent a dilute sewage.

Several important experiments with regard to the filtration of sewage through various materials were made under the direction of the Rivers Pollution Commissioners.* They pointed out in the first place that "the water-bearing gravel of London is supplied almost exclusively by sewage, and the water pumped from the shallow wells in London is little else but filtered sewage;" and, to show the extent of purification which this water undergoes, it is found that it contains very little organic nitrogen and carbon, and very little ammonia, but, instead, a considerable proportion of nitrates and nitrites. Experiments conducted by filtering London sewage through 15 feet of

London well-water.

* First Report, R. P. C., 1868, vol. i. pp. 60-70.

sand showed that, in the first place, "the process of *upward* filtration through sand is inefficient in the purification of sewage from soluble offensive matters . . . on no occasion was the effluent water in a condition fit to be admitted into running streams."

Filtration experiments.

This result is confirmed by the observations of the Committee of the British Association, who examined the process of upward filtration through gravel at Ealing. It was found that this process, whether accompanied or not by the addition of a deodorising mixture to the sewage in the sewers of the town, "effected only a very slight purification of the sewage, which left the filter still a sewage of average strength. It was not even clarified." (*Report*, 1873, p. 443.)

Upward filtration.

The experiments of the Rivers Pollution Commissioners showed that

> The process of intermittent *downward* filtration through either sand or a mixture of chalk and sand, effects a very satisfactory purification of sewage when the sewage treated amounts to 5·6 gallons per cubic yard of filtering material in twenty-four hours, but that the purification becomes uncertain and unsatisfactory when the rate of filtration is doubled, that is when the sewage treated amounts to 11·2 gallons per cubic yard in twenty-four hours. These experiments also show that the process of purification is essentially one of oxidation, the organic matter being to a large extent converted into carbonic acid, water, and nitric acid; hence the necessity for the continual aëration of the filtering medium, which is secured by intermittent downward filtration, but entirely prevented by upward filtration.

Rationale of process.

In fact, it was found that, by downward filtration through soil, the organic carbon and nitrogen were reduced to about the proportions in which they are found in the London drinking waters, viz. from ·5 to ·7 of carbon, and ·06 to ·07 of nitrogen in 100,000 parts; the original amounts in the sewage having been 2·48 of organic nitrogen and 4·38 of organic carbon. On the other hand, the amount of nitrogen as nitrates and nitrites was increased from

Amount of purification.

nothing to from 3 to 5 parts in 100,000. "Only as a source of drinking water could a stream into which such purified sewage flows be condemned." Some further experiments on downward filtration through the Beddington soil, which were conducted in glass cylinders, showed that "the effluent water was always clear and nearly colourless, at the rate of 3·8 and 7·6 gallons per cubic yard per diem. In respect of organic matter the filtered sewage actually equalled, or even surpassed in purity on four occasions, the water which is sometimes supplied to London for domestic purposes." Further experiments showed that the results are very different with different soils, and that in some cases the nitrogenous matters are absorbed and retained as such, without being converted into nitrates and nitrites, and that this result does not apparently depend upon the presence or absence of light, or upon variations in the temperature.

Quality of effluent water.

Intermittent downward filtration is then a valuable method for the purification of sewage, but not for the utilisation of it, as the area of ground is too small and the quantities of sewage turned on to it too large.

It was found that the "light yellowish brown loam from the marlstone of the lower oolite near Dursley, in Gloucestershire," surpassed all the others experimented upon in its power of purifying sewage:—

Values of different soils.

Whilst one cubic yard of sand, or of Hambrook soil, cannot continuously and satisfactorily purify more than 4·4 gallons of London sewage per twenty-four hours, one cubic yard of Beddington soil can cleanse 7·6 gallons, and one cubic yard of Dursley soil no less than 9·9 gallons in twenty-four hours, which is equivalent to the cleansing of nearly 100,000 gallons of sewage per day by an acre of this soil, provided the drains for the effluent water are 6 feet deep. (*Loc. cit.* p. 69.)

It would appear that the physical condition as regards porosity and fineness of division has more to do with the cleansing power of a soil than its chemical composition has. "At the conclusion of the long series of experiments there were no symptoms of clogging up or diminution of activity, and the effluent water was always bright, inodorous, and nearly colourless." It was found that with Lancashire peat as a filter, the effluent water was not much purified at first, but afterwards steadily improved, giving a "hope that this material would, after a somewhat higher education, become an efficient purifier of sewage filtered through it at the rate of 4 gallons per cubic yard per twenty-four hours." The Commissioners consider that with a properly constituted soil, deeply drained, and divided so that the sewage could be applied on one part at a time, "the sewage of a water-closet town of 10,000 inhabitants could, at a very moderate estimate, be cleansed upon 5 acres of land." Results with peat.

The facts concerning nitrification or the conversion of ammonia and the nitrogen of organic matter into nitric acid in the soil, upon which process the purification of sewage largely depends, were fully brought to light in a paper read by Mr. R. Warrington before the Society of Arts in 1882. We may quote the following passages from Mr. Warrington's paper:—

Mr. Warrington's paper on nitrification.

Dilute solutions of urine, or of ammonium salts, containing the essential constituents of plant food, undergo no nitrification, though freely exposed to the air, if only they have been previously boiled and the air supplied to them is filtered through cotton wool. If to such sterilised solutions a small particle of fresh soil is added, no action at first appears, but after a while active nitrification sets in, and the ammonia or urea is converted into a nitrate. For the production of nitric acid it is necessary that some base should be present with which the nitric acid may combine. The action proceeds best in the dark. When a solution has thus undergone nitrification, a drop of it suffices to induce nitrification in another solution, which, unless thus seeded, would have remained unchanged. Boiling the soil, or the solution that has nitrified, entirely destroys its power of causing nitri- Presence of a base necessary.

fication. The presence of antiseptics also prevents nitrification. Lastly, nitrification is confined to the same range of temperature which limits other kinds of fermentation. The production of nitrates proceeds very slowly near the freezing point, but increases in rapidity as the temperature rises, reaching its maximum of energy, according to Schlœsing and Müntz, at 37° C. (99° Fahr.) At higher temperatures the rate of nitrification rapidly diminishes ; it almost ceases, according to the same observers, at 50° C. (122° Fahr.), and at 55° C. (131° Fahr.) no change occurs. It thus appears that nitrification can only be produced in the presence of some nitrified or nitrifying material, and the whole course of the action is limited to the conditions suitable for the activity of a living ferment. The French chemists claim to have isolated the ferment by systematic cultivation ; it belongs to the family of *Bacteria*.

Influence of temperature.

The purifying action of soil on sewage is probably due to three distinct actions. 1. Simple filtration, or the separation of suspended matter. 2. The precipitation and retention by the soil of ammonia, and various organic substances, previously in solution. 3. The oxidation of ammonia and organic matter by the agency of living organisms. The last mode of action is undoubtedly the most important, as without oxidation the sewage matter must accumulate in the soil, and the filter bed lose its efficacy. The filtering power of a soil will depend entirely on its mechanical condition. The precipitating power of soil is, on the other hand, a chemical function, in which the hydrated ferric oxide and alumina, and the silicates of soils probably play the principal part. The oxidising power of a soil will depend partly on its mechanical, partly on its chemical, and partly on its biological condition. It was formerly supposed that the oxidising power of a soil depended solely on its porosity, oxidation being assumed to occur by simple contact with air in the pores of the soil. We now know that a porous medium is by no means essential for nitrification ; sewage may, indeed, be nitrified in a glass bottle, or when passing over polished pebbles. Though, however, porosity is by no means essential to the nitrifying power of a soil, it is undoubtedly a condition having a very favourable influence on the rapidity of the process ; a porous soil of open texture will present an immense surface, covered with oxidising organisms, and generally well supplied with the air requisite for the discharge of their functions. It is doubtless owing to this fact that nitrification takes place with so much greater rapidity in a soil than in a liquid. The sewage will itself supply the substances required for the nourishment of the oxidising organisms. One material essential to nitrification may, however, sometimes be deficient, namely, the base with which the nitric acid is to combine ; without the presence of this salifiable base, nitrification will speedily come to a standstill. In the case of towns supplied with hard water, the sewage may contain as much carbonate of calcium in solution as will suffice for its subsequent nitrification in the soil ; but in the case of towns supplied with very soft water, this can hardly be the case, and

Oxidising power of a soil.

the presence of a considerable amount of lime in the soil itself will become essential for efficient nitrification. The organisms which effect the oxidation of organic matter are abundantly present in surface soils, but are probably absent, or nearly so, in subsoils; in surface soils they will probably be abundant in proportion to the richness of the soil in organic matter. Sewage also contains the organisms necessary for its own destruction, and under favourable conditions these may be so cultivated as to effect the purpose. A filtering medium of pure sand and limestone, treated intermittently with sewage, will, after a time, display considerable purifying powers, the surfaces becoming covered with oxidising organisms derived from the sewage. No such medium will, however, equal in effect a porous soil, rich in organic life. It will be gathered from the observations now made that it would be possible to construct a filter bed having a greater oxidising power than would be possessed by an ordinary soil and subsoil. Such a bed would be made by laying over a system of drain-pipes a few feet of soil, obtained from the surface (first 6 inches) of a good field, the soil being selected as one porous, and containing a considerable amount both of carbonate of calcium and organic matter. A filter bed thus prepared would be far more porous than a natural soil and subsoil, and would possess active oxidising functions throughout its whole depth. The oxidising power of soil must always be considerably greater in summer than in winter. The favourable influence of the warmer seasons of the year is apparently seen in several of Frankland's experiments on the intermittent filtration of sewage; the same influence of temperature will be plainly shown in some of the Rothamsted results. When we turn, however, to the analyses of the effluent water from irrigated land, the fact is not always manifest. We must recollect, however, that a considerable part of the nitrates produced in summer will be assimilated by the growing crops, and will therefore not appear in the drainage water. The oxidising power of a soil may also be in excess of the work provided for it, so that even with a low temperature the usual amount of purification may be attained. A low temperature will also affect only the oxidising functions of soil, its power of precipitating and retaining sewage matter will remain unchanged. One more point may be worth notice. We have already referred to the fact that nitrification, like all other kinds of fermentation, ceases in the presence of antiseptics; the refuse of chemical works may thus, sometimes, prove a great hindrance to the purification of sewage by soil. (*Journal of the Society of Arts*, April, 1882.)

Organisms in surface soils.

Construction of a filter bed.

Nitrates assimilated by crops.

Later researches have shown that the nitrifying organisms exist in soils to a greater depth than was previously thought to be the case, viz. to 3 or 4 feet from the surface, and that gypsum or sulphate of lime in the soil or sewage greatly aids the nitrifying action.

Intermittent downward filtration at Merthyr-Tydfil.

The Committee of the British Association examined the process of intermittent downward filtration at Troedyrhyw, near Merthyr-Tydfil, where an area of about 20 acres has been converted into a filter-bed for the purification of the sewage of the town of Merthyr-Tydfil. (*Report*, 1873, pp. 443, 444.)

The soil consists chiefly of gravel and sand having a vegetable mould on the surface. It is extremely porous. The land is drained at a depth of less than 7 feet, the drains being brought together at the lowest corner, where the effluent water is discharged into an open drain leading to the river Taff. The area is laid out in square beds intersected with roads and paths, along which are constructed the main carriers which receive the sewage from the outfall-sewer and distribute it over the beds. The sewage, after being screened through a bed of "slag," in which the larger suspended matters are arrested, is turned on to one of the four plots into which the area is divided, and allowed to run on this plot for six hours, when it is turned on to another one. Thus each of these four plots has eighteen hours for rest and aëration of the soil. The surface of the area is laid up in ridges, and cabbages and other vegetables planted along them, the sewage running in furrows between. The main results of the examinations which took place in January and in July, extending over seven and eight days respectively, were :—that the effluent water discharged was very largely diluted with subsoil water which had percolated through from the river bed (this was proved both by the gaugings and by the analyses, and had been already observed by the Rivers Pollution Commissioners); that the effluent water was very satisfactorily purified, the nitrogen in solution appearing in the form of nitrates and nitrites, a sufficient proof that a considerable amount of oxidation goes on in the filter-beds. Upon a comparison of the total nitrogen in solution in the sewage, in the effluent water, and in the subsoil water (which was also analysed), it was found that the amount in the effluent water was almost exactly the amount that would be present in the sewage if diluted with the amount of subsoil water (rather more than its own volume) with which the analyses and the gaugings showed it to have been diluted ; that is to say, that a quantity of nitrogen, equal to the amount in solution in the sewage, escaped in the effluent water and was lost (escaping, however, almost entirely in the oxidised and innocuous form of nitrates, etc.), the amount retained in the soil and by the plants being, therefore, equal to the amount in the suspended matters of the sewage. The effluent water was not quite so pure in the summer as in the winter : in the former case four-fifths and in the latter twelve-thirteenths of the nitrogen contained in it was in the form of nitrates and nitrites. The sewage was cooled by its percolation through the soil ; in the winter from 48° Fahr. to 46° Fahr. (the temperature of the subsoil water

Sewage oxidised in the filter-beds.

Sewage cooled by passing through the soil.

being 42° Fahr.), and in the summer from 60° Fahr. to 55° Fahr. The crops grown on the surface of the filter-beds were successful and realised very good prices.

The process of intermittent downward filtration was examined by the Committee of the Local Government Board (Appendix to *Report*, pp. 32, 33) at Kendal. The sewage of the town is received into subsidence tanks, and thence flows on to 5 acres of land laid out as filter-beds, and occasionally, as required, on to 11 acres of land, not so laid out but levelled. The volume of sewage is about 750,000 gallons daily, of which about 350,000 gallons are subsoil water from springs tapped during the execution of the sewerage works. This small area clarifies the sewage so as not to be a nuisance, but in practice it is found too limited for crops to be successfully grown on it, and therefore an additional area of 5 acres has been prepared for the reception of the sewage, and it is believed that "upon the 10 acres of filter-beds not only will the foul waste of the inhabitants and refuse from manufactories and dye-works be properly cleansed, but that sufficient crops will be grown upon the land filter-beds to pay the annual expenses of thus utilising the sewage." The soil of the farm is a very fine sandy loam upon a subsoil of gravel, and the effluent water filtering through this into the river is bright and clear.

Intermittent downward filtration at Kendal.

Area too limited for crops to be grown.

Soil of the farm.

The Royal Commissioners on Metropolitan Sewage Discharge (*Second Report*, p. 46) define the difference between the intermittent filtration system and that of ordinary broad irrigation as follows: "Broad irrigation means the distribution of sewage over a large surface of ordinary agricultural ground, having in view a maximum growth of vegetation (consistently with due purification) for the amount of sewage

Definition of broad irrigation.

Definition of filtration.

supplied. Filtration means the concentration of sewage, at short intervals, on an area of specially chosen porous ground, as *small* as will absorb and cleanse it; not excluding vegetation, but making the produce of secondary importance. The intermittency of application is a *sine quâ non* even in suitably constituted soils, wherever complete success is aimed at."

Intermittent application a *sine quâ non*.

Objections to the intermittent filtration system.

The Commissioners in considering the subject of intermittent filtration through land state the objections to the system to be as follows:—"First that the plan is wasteful, as not fitted for producing crops," and they show that if for each acre the number of people be limited to 1000, crops can be grown, as at Kendal, where out of the 10 acres used intermittently for filtration 4 acres grow cabbages, 2 mangold, 2½ carrots, and the remainder miscellaneous garden produce. The number of people to an acre at Kendal is 850, and the effluent is said to be "good, clear, and colourless." Secondly it was suggested that "the collection of the solid matters of the sewage might give rise to a formidable nuisance, especially in hot weather, and might clog the pores of the land so as to prevent proper filtration."

Need not be wasteful.

The Commissioners say:—

The solid matters of the sewage should be separated.

> Experience has not warranted these fears, but at the same time it appears to be advisable previously to separate the solids to some extent. It is certain that the more the liquid approaches clarification, the less land will be required, and the less danger will there be of unpleasant odours. For a small number of people, say under 500 to the acre, the sewage may be applied as it comes, leaving the grosser matters to be amalgamated with the soil. But if the number be increased, the previous removal of the sludge would be desirable, and for 1000 or more, it would probably become absolutely necessary.

Cost of preparing the land.

The cost of preparing land for filtration, it is stated, "must be greater than that for broad irrigation; but when the tenfold efficiency of each acre in doing work is taken into account, this can be well afforded." Mr. Bailey Denton puts the average at about £70 per acre.

The Commissioners were of opinion (p. 48) that

In filtration ground properly laid out there ought to be no communication between the influent and the effluent channels, except through the pores of the land, so that the sewage, in order to get away, must necessarily pass through the filter. By this means the process of purification becomes not optional (as in broad irrigation) but compulsory. And supposing the persons working the farm had at any time an inducement to pass away the sewage unfiltered, they could hardly do so without such a derangement of the works as would attract immediate attention.

Purification compulsory.

In regard to the *liability to objection*, the Commissioners believe that "this process has the advantage over broad irrigation. For the liability of nuisance would, if the sludge were previously removed, be reduced by the smaller area of land exposed; and the danger to subsoil waters would be diminished by complete and skilful under-drainage."

Liability of nuisance less than in broad irrigation.

Mr. Bailey Denton states in his work on "Intermittent downward Filtration," 1885 (p. 44), that "if properly distributed on carefully prepared surfaces, sludge on land generally does good rather than harm; in fact, it only has an objectionable effect when it is mixed with particular trade refuse." He advises filtration beds to be laid out in ridges and furrows, and vegetables to be grown on the ridges.

Sludge applied to land.

As soon as the deposit of sludge on the sides of the furrows is sufficient to prevent infiltration in any great degree, the sewage is withheld from the areas so affected. The sludge is then allowed to dry (partially) in the furrows, and when in a fit condition it is lifted and dug into the ridges—as can be seen practised at Gennevilliers (Paris). The slimy matter which had appeared so considerable, and which puddled the bottom of the furrows when in a wet state, shrinks to a skin of very insignificant thickness when dry, and is readily broken up and mixed with the soil. Experience has shown that sludge (with such fertilising ingredients as it contains) cannot be more cheaply conveyed to places where it would be beneficial than by the

Deposit in furrows.

Plants on ridges not fouled.

liquid sewage itself. . . . The objection raised to the distribution of sewage containing solid ingredients in suspension amongst growing plants, because the solid matters will cling to their stalks and leaves, vanishes altogether when furrows are made the channels of distribution, and when no more sewage is distributed on the surface of land than the land will absorb and vegetation requires (pp. 44, 45).

Dr. Tidy has expressed the opinion that one acre of suitable land is sufficient to purify the sewage of 5000 to 7000 people, if previously efficiently precipitated. ("The Treatment of Sewage," *Journal of the Society of Arts*, October 1886.)

Recommendations of the Commissioners.

The Metropolitan Sewage Discharge Commissioners recommended, as the best method of solving the difficulty of the metropolitan sewage discharge, the deposition or precipitation of the solid and suspended matters of the sewage by chemical treatment, and the subsequent application to land of the liquid portions of the sewage by a process of intermittent downward filtration; the precipitated sludge to be applied to the raising of low-lying lands, or burnt, or dug into the ground, or carried away to sea. The purified effluent could not pollute the river and injure the fish, and contamination of the subsoil waters would be avoided.

Clay land as filter beds.

Where it is desired to treat sewage on clayey land by intermittent downward filtration, a good filter bed can be constructed at a cost of about £600 to £800 per acre by burning the clay into ballast and laying down the ballast to a depth of about 3 feet with layers of alluvial or other rich soil interposed. Nitrification, which has been shown to be the principal process in the purification of sewage by land, takes place in the upper layers of the soil, not extending much below 3 feet from the surface, so that a total depth of properly prepared filtering area not exceeding 4 feet in depth will be found sufficient in many cases.

CHAPTER XI

IRRIGATION

We find, then, from the foregoing chapters, that, given town sewage, the only way that has yet been discovered of purifying it is by *intermittent downward filtration* through a certain thickness of soil, and that soils vary very considerably in their power of so purifying it. Some soils appear to absorb the organic matters contained in sewage water in a very perfect manner, and allow but little escape of valuable matter in any form in the effluent water; others still purifying the sewage, but doing so especially by the rapid oxidation of ammonia and organic nitrogenous matters, attended with the formation of nitrates and nitrites which escape in solution in various quantities in the effluent water, and which, although perfectly inoffensive in themselves, still represent so much loss of valuable matter. "A filter is not a mere mechanical contrivance; it is a machine for oxidising and thus altogether transforming as well as for merely separating the filth of dirty water." It is plain that a certain quantity of soil can only do a certain amount of work in this way; that if too much sewage be poured on to it, a certain amount of the organic materials must necessarily escape oxidation, and the effluent water will flow away unpurified. In all the filtration ex-

Introductory remarks.

Functions of filter.

periments this is found to be the case: when the flow exceeds a certain quantity or a particular rate, the effluent water invariably contains undecomposed organic matters. Thus we see that, as far as the question of purification goes, it is desirable to extend the area of the filter as much as possible; the more this is done the purer the effluent water will necessarily be; but as besides the question of purifying the sewage, there is also that of utilising it, the area over which it is applied must be limited in order that if possible a sufficient agricultural return may be produced to pay the expenses of working the system and to ensure the realisation of a profit. The first thing to be attained is the purification of the sewage to such an extent that the effluent water may be safely allowed to flow into a watercourse; the next is the application of it as an agricultural manure in such quantities and in such a manner as to realise the greatest returns per ton of the sewage and per acre of land; and the last, to do this in such a manner that the health of the inhabitants of the irrigated districts shall in no way be affected injuriously by the process.

Filter should be enlarged.

Three conditions to be satisfied.

The question then arises, does sewage, as at present applied to land for agricultural purposes in various places, become so purified that the effluent water is untainted by fæcal matter? Let us examine the results of analyses which have been made at various places of sewage applied to the land, and of the water which flows away in the drains of that land.

But we must here premise that the earlier analyses of this nature are not at all to be relied on, as the methods of water analysis were very imperfect, that of estimating the amount of organic matter in the total solid residue by incineration being entirely fallacious. From the First Report of the Rivers Pollution Commissioners we find that the raw sewage supplied to the Craigentinny meadows, near Edinburgh, contained 3·613 parts of organic nitrogen and 9·510 of ammonia in 100,000 parts, while the effluent water contained ·682 of organic nitrogen and 1·989 of ammonia; this being produced by the flow of about 700 tons of sewage per hour over less than 2½ acres of land during an hour and a half, the general result being the reduction of the total combined nitrogen from 11·445 parts to 2·320, and of the total suspended matters from 39·40 to 5·52 parts per 100,000. This, it must be remembered, is the result produced by the application of enormous quantities of sewage to a limited area. The value of the agricultural products having been alone kept in view, it "must not be quoted as a successful example of sewage cleansed by irrigation, . . . for it is poured over them (the meadows) in such enormous quantity that the soil has not fair play given to it as a cleanser, and the water therefore leaves the grass-land still filthy and offensive." It must be noted that here there are no nitrates and nitrites in the effluent water. (*Loc. cit.*, vol. i. pp. 74, 75.)

Comparison of sewage and effluent water;

under unfavourable circumstances.

At the Lodge Farm, near Barking, where the soil is gravelly and very pervious, so that the water cannot travel far upon the surface, and "that after fifty yards at most of surface-flow it sinks, to reappear only at the mouth of the main drain of the farm," it was found that the organic nitrogen was reduced, during fifty or sixty yards of surface-flow, from 3·664 to 1·872; after a further surface-flow, to ·624; and, at the issue of the main drain of the farm, to ·329 parts per 100,000; the ammonia being reduced during the same flow from

Better results.

Appearance of nitrates and nitrites.

4 to ·8 parts per 100,000, while the nitrates and nitrites, which were absent from the sewage, appeared in the effluent water to the extent of nearly 3 parts per 100,000. Plenty of other instances might be taken, all of them showing that the amounts of each and all of the constituents of sewage are considerably reduced by practical irrigation, with the exception of chlorine, which is very slightly reduced, or even sometimes apparently increased, and nitrates and nitrites, which, not existing in the sewage itself, appear in the effluent water, sometimes in considerable quantities; and these results have been obtained even where the object has not been so much the purification of the sewage as the production of a valuable agricultural return. We can go still further than this, and say that *the constituents which are most effectually removed from the sewage are especially the putrescible organic matters;* that is to say, are those which it is our main object to remove both from a sanitary and an agricultural point of view. We have already seen that all other processes especially fail in removing these very constituents. With regard to these analyses, however, we must note that the amount of the purification is presented to us by them in an exceedingly unfavourable manner. In all the processes of mere straining or precipitation the amount of effluent water is to all intents and purposes the same as the amount of sewage, and the number of parts of each of the constituents per 100,000 may be fairly compared with the number of parts of the same constituents in 100,000 parts of sewage. But with irrigation the case is totally and entirely different; the amount of effluent water issuing from the drains of an irrigated piece of land, on which crops are growing, is diminished not only by the amount

Effectual removal of putrescible matters.

Results really even better than they appear to be.

that directly evaporates from the soil itself, which in dry weather must be very considerable, but by the enormous amount that is continually evaporating from every exposed part of the growing plants. This enormous amount will be the more appreciated when we consider the results of its cooling power on a somewhat extended scale.

Enormous evaporation from plants.

Many are the instances in which the climate of a country has been entirely changed by the destruction of its forests, but we need only state the case of the destruction of many of the large forests which formerly bordered the banks of the Rhine, by which the climate has been changed from a very cold one to a temperate one, the winters never now having anything like the severity they had in former times, when that river was frequently frozen over (Blumenbach). This continual evaporation, then, causes a very considerable diminution in the amount of water which can possibly flow away by the drains as effluent water. To determine accurately the amount of this loss would require a special set of observations under such conditions as would ensure the collection of the whole of the effluent water. Such experiments have been carried out by the Committee of the British Association at Breton's farm, near Romford, and the results of them will now be given.

Illustration.

Experiments on amount of loss of water.

The Committee determined that the average amount of diluted sewage pumped on to Breton's farm per diem was 1182 tons; this being the average of over a year's (399 days) observations. The average amount of effluent water discharged was found to be 513½ tons per diem, that is to say, only 47·3 per cent of the sewage pumped on to the land is discharged through the deep drains as effluent water. The rain-

Proportionate amounts of sewage and effluent water.

fall at the farm during the 399 days was 22·64 inches, equal to 2287 tons per acre, or on the 121½ acres of the farm 277,900 tons (*Report*, 1871, p. 176). As to the composition of the sewage and effluent water, the average amount of nitrogen in 100,000 tons of the diluted sewage pumped was 5·529 tons; that in the effluent water 1·147 ton; and as the volume of the effluent water was only 47·3 per cent of the total amount of diluted sewage applied to the land, it follows "that the proportion of nitrogen escaping in the effluent water to the total quantity applied is ·1067, or about one-tenth." It is very important to observe that *the analyses were made of average samples—that is to say, of samples taken in proportion to the rate of flow of the sewage at the times, as indicated by the gaugings.*

Quantities of nitrogen in sewage and effluent.

The following table is calculated from results given in Table II., *Report*, 1873, p. 420:—

Average Composition of Sewage as pumped on to Breton's farm from March 1872 *to March* 1873, *and of Effluent Water.*

Results given in parts per 100,000.
NITROGEN.

	In Solution.				In Suspension.	Total in Solution and Suspension.
	As Ammonia.	Organic.	As Nitrates and Nitrites.	Total.		
Sewage .	2·6	1·05	0	3·65	1·75	5·4
Effluent .	·072	·147	·947	1·166	0	1·166

These results show that we must not consider, because we find a certain quantity of organic nitrogen, of ammonia, of nitrates and nitrites, etc., in 100,000 parts of effluent water, that this quantity came from only 100,000 parts of sewage. The analytical results obtained by the Rivers Pollution Commissioners, which we have already given have certainly never been approached by any other method than that of filtration through land, and for reasons already given it is hardly possible that they ever will be, so that they are very favourable to irrigation as a means of purifying the sewage: making the correction indicated, they become indeed exceedingly favourable. It appears, then, that the first requirement is satisfied by irrigation, and this is borne out by the opinions expressed in all the Reports that have been issued upon the subject. The Sewage Commissioners, in their First Report (1858), showed that they considered that the irrigation of land (in some cases supplemented by other processes) was the best means of preventing the pollution of streams by sewage. In their Third Report (1865), p. 3, they state still more definitely that "the right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

Results favourable, even without allowance for evaporation.

First condition satisfied.

We must at once insist upon the condition of filtration, which is an absolutely essential one in any attempt at the purification of sewage. The success of the irrigation process entirely depends upon this. It is not sufficient to let the sewage run over the surface of the land among the crops, and to suppose that it may be purified in this way; it must not merely run on to the land, but also *through it*.

Must not run merely over the land.

The Committee of the British Association made a special investigation of these points, and the results as abstracted for the Committee by the author are here given (*Report*, 1873, pp. 445, 446) :—

At the farms at Tunbridge Wells, where the sewage is applied to the surface of the land on the catch-water system, and where under-drainage has not been systematically carried out (the drains which already exist having, in fact, been brought up to the surface to empty into the carriers), the purification of the sewage cannot be said to be

Catch-water system.

satisfactory; for although a considerable dilution with subsoil water takes place, the water which has passed over the land is still impure, and moreover, contains scarcely any nitrates, thus showing that very little oxidising action takes place.

Very little oxidation.

The same result was found at the Reigate farm at Earlswood,* where the state of the effluent water was still more unsatisfactory; in fact, in one instance, it was found that the sewage which had passed over two fields was actually stronger, except as regards actual ammonia (*i.e.* it contained more of the total solids in solution, with more nitrogenous organic matters), than it was after passing over only the first of these fields, thus showing that the ground was so saturated with sewage that any additional sewage passed on to it could "only concentrate itself by evaporation, or by solution of matters in the upper layer of the soil."

Sewage rendered stronger.

These farms were again inspected in the following year. It was found that the effluent water was running clear and free from smell. No analyses were however made at this time. The crops included oats, beans, and wheat, as well as meadow-grass and Italian rye-grass, and seemed to be in a satisfactory condition; but no general system ot subsoil drainage had been commenced. A comparison was made in January 1871, during severe frost, of the results obtained in the purification of sewage at the three following farms:—Breton's farm, near Romford, Beddington farm, Croydon, and Norwood farm. It was found that in the latter two cases, where the sewage was passed over the land on the catch-water system, it was not satisfactorily purified, the nitrogen escaping in the effluent water being only partially in the state of nitrates and nitrites; while in Breton's farm, where the sewage passes through the soil, the farm being in effect a large filter-bed, "(1) oxidation goes on in winter as well as in summer, and almost all nitrogen lost is lost in an oxidised and inoffensive form; and (2) this loss is very slightly greater in winter with a very strong sewage than in summer with a weaker one, so that sewaging in the winter would appear to entail no extra loss of manure."

Comparison of catch-water and filter-bed systems.

It was also observed that while in summer sewage is cooled by percolation through the soil, and almost always heated (sometimes considerably so) by surface-flow, as was observed both at Tunbridge Wells and at Earlswood (the temperature of the effluent water in the latter case being actually 5° higher than that of the sewage), in winter, on the other hand, the cooling which takes place is less with percolation through the soil than with surface-flow in both instances, so that "these results are favourable to percolation through the soil, as opposed to mere surface-flow both in summer and winter. Percolation causes a considerable cooling in summer, while in winter it does not cool the effluent water so much as surface-flow does."

Percolation preferable to surface-flow.

These results induced the Committee to make the

* Where none of the land is underdrained.

following distinct statement in their Third Report, p. 185 :—

> It may seem almost superfluous for the Committee, after so many years of general experience throughout the country, to argue in favour of the subsoil drainage of naturally heavy or naturally wet land with impervious subsoil for purposes of ordinary agriculture; but some persons have strongly and repeatedly called in question the necessity of draining land when irrigated with sewage; and the two farms at Tunbridge Wells, to a great extent, and more especially the Reigate farm at Earlswood, have been actually laid out for sewage irrigation, on what may be called the "saturation principle;" so that it appears to the Committee desirable to call attention to the fact, that if drainage is necessary where no water is artificially applied to the soil, it cannot be less necessary after an addition to the rainfall of 100 or 200 per cent. But a comparison of the analyses of different samples of effluent waters, which have been taken by the Committee from open ditches into which effluent water was overflowing off saturated land, and from subsoil drains into which effluent water was intermittently percolating through several feet of soil, suggests grave doubts whether effluent water ought ever to be permitted to escape before it has percolated through the soil.

Farms laid out on the "saturation principle."

Comparison of analyses.

The power of the crops themselves of abstracting the manurial constituents from the sewage is doubtless exceedingly great, but it must be remembered that this power chiefly resides in the roots, and that as the soil itself has been proved capable of abstracting these manurial constituents, *à fortiori* will this be done the more completely when the soil is aided by the avidity of the roots of a growing crop to absorb their natural nutriment. The process is, in fact, one of direct conversion of refuse matters into crops; these matters being brought for the most part dissolved in water, that is to say, in the natural condition in which, as far as yet known, they are really capable of being absorbed by plants: although the power of the soil itself (that is, of certain soils) to retain these manurial matters must not be overlooked; neither must the fact that the roots of plants are capable of doing it when the soil is of such a quality that it would not

Sewage must come in contact with the roots;

is absorbed by them when soil itself could not retain it.

do so to any appreciable extent, and when indeed the plants could not be grown upon it at all if it were not supplied with manure continually. That is to say, that despite the weighty authority of Baron Liebig, who has maintained the contrary opinion, indisputable facts have most certainly shown that pure sand is capable of supporting large crops when properly supplied with a sufficient quantity of sewage. In the Appendix to the Special Report from the Select Committee on the Thames Navigation Bill, the result of an experiment is stated which showed that Italian rye-grass, wheat, and mangolds could be perfectly well grown on sea-sand ($2\frac{1}{2}$ feet in depth) when sewage was properly supplied to it. The lower portion of the present Craigentinny meadows consisted, fifty years ago, of low moving sandhills, the "Figgate Whins." In fact, it is now useless to deny that sea-sands may in this way be reclaimed and made valuable property, producing annually enormous crops of grass. That it is not advisable to apply the sewage to lands which cannot absorb it independently of the crops, we do not for a moment wish to maintain; it is plain that when applied to fallow land, as it would often have to be, especially in winter, it is essential that the soil should thoroughly absorb and retain the manurial constituents, or at any rate it must be demanded that they shall be so thoroughly oxidised that the effluent water shall retain none of them in a putrescible condition. But that crops will grow on lands so absolutely worthless that the soil only performs the function of mechanically supporting the plants, if they be supplied with the organic and inorganic matters essential to their growth, and which are contained in town sewage, is now an ascertained

Crops grown on sea-sand.

Best soils those which can retain the manure.

fact. The condition, then, is simply that the sewage be not allowed to run merely over the land, but through it, so as to come in contact with the roots of the plants. To this end it must be applied *from the surface*, and not by underground pipes, as in this latter case it is plain that it would not wash the roots of the plants, as it is delivered into the soil for the most part below them. Sewage must come in contact with the roots.

In the Report of the Select Committee on the Metropolis Sewage (known as Lord Robert Montagu's), 1864, it is stated that

> No efficient artificial method has been discovered to purify, for drinking and culinary purposes, water which has once been infected by town sewage. By no known mechanical or chemical means can such water be more than partially cleansed ; it is always liable to putrefy again. Processes of filtering and deodorisation cannot therefore be relied upon to do more than mitigate the evil. Water which appears perfectly pure to the eye is sufficient, under certain conditions, to breed serious epidemics in the population which drinks it. . . . Soils, however, and the roots of growing plants, have a great and rapid power of abstracting impurities from sewage water, and rendering it again innocuous and free from contamination. (*Report*, p. 6.) Conclusions of Committees.

And again, in the First Report of the Committee on the Sewage of Towns, 1862 (known as Dr. Brady's), we find the conclusion arrived at by Dr. Hofmann, "that all proposals to use sewage, except the proposal to use it for purposes of irrigation, bore in themselves evidence of their impracticability." And in the First Report of the Rivers Pollution Commissioners (1868), vol. i. p. 71, it is stated as the result of the numerous and important experiments conducted by the members of that Commission, that

> Considered merely as a mechanical and chemical agency for cleansing the drainage water of our towns, it seems plain that a sufficient extent and depth of porous soil to be used in irrigation, having periodical intervals of rest, during which the soil drains and becomes refilled with air, certainly must be the best possible strainer, oxidiser, and filter of water which, like the sewer water of our towns, contains nauseous organic impurities both suspended and dissolved. That porous soil is the best purifier.

The British Association Sewage Committee arrived at the conclusion that "by properly conducted sewage irrigation a solution is afforded to the question of sewage utilisation" (*Report*, 1873, p. 450). They further state that

That sewage should pass through the soil.

In all instances it is essential that the land should be well underdrained, and that the sewage should all pass through the soil, and not merely over it; otherwise, as has been shown, it will only occasionally be satisfactorily purified. The catch-water, or, as the Committee has termed it, the supersaturation principle, is not defensible, either on agricultural, chemical, or sanitary principles. An irrigation farm should therefore carry out intermittent downward filtration on a large scale, so that the sewage may be always thoroughly purified, while at the same time the maximum of utilisation is obtained.

The conclusion arrived at by the Committee of the Local Government Board on Modes of Treating Town Sewage was (*Report*, 1876, p. 13) that

Town sewage can best and most cheaply be disposed of and purified by the process of land irrigation for agricultural purposes where local conditions are favourable to its application.

One of the results of the Society of Arts Conference on the Health and Sewage of Towns (1876) was expressed by the Committee as follows:—

In certain localities, where land at a reasonable price can be procured, with favourable natural gradients, with soil of a suitable quality, and in sufficient quantity, a sewage farm, if properly conducted, is apparently the best method of disposing of water-carried sewage. It is essential, however, to bear in mind that a profit should not be looked for by the locality establishing the sewage farm, and only a moderate one by the farmer.

EXAMPLES OF SEWAGE FARMS.

We will now bring forward some examples to show what has been done already in the practical application of sewage water as manure by irrigation. The number of towns which now utilise their sewage in this manner is very large, and it would be impossible even if it were desirable to give examples of them all in the present work. The examples given in the first and second editions of this work have been retained in the present edition, as they were the pioneers of a system which has now been so largely adopted, and it was on their success or failure to satisfy sanitary and commercial requirements that the future of sewage farming so largely depended. An account of the Birmingham sewage farm, to which we paid a special visit in company with Mr. Alderman Avery, has been added.

The Health of Towns Commissioners, in their First Report (1844), give a short account of irrigation as applied at Milan; the Sewage of Towns Commissioners, in their Preliminary Report (1858), give a somewhat longer account of it; and from these two Reports we gather the following particulars. The city is chiefly supplied with cesspools; there are very few water-closets, and they communicate with cesspools. Irrigation at Milan.

It is forbidden to discharge urine into the drains, but there being so direct an interest against the discharge of any fluid into the cesspools (because the inhabitants have to pay for emptying them), it may readily be supposed that no more than is unavoidable finds its way into those receptacles, and that as the streets themselves abound with urinals, the chief portion of this valuable part of the refuse of the town does find its way to the sewers. (*Prelim. Report S. of T. C.*, p. 40.)

The liquid refuse of the city is collected in large sewers, which join one another and meet in a canal called the "Vettabbia." This "is made to ramify and serve for the irrigation of about 4000 acres of land, after which it falls into the River Lambro, about ten miles below the city." And here we find a remarkable instance of the truth of a fact before stated, namely, that the separation of the solid excremental matters from the sewage does not to any appreciable Sewage without solid excrement.

extent diminish its manurial value, or prevent its being to all intents and purposes sewage—a liquid containing large quantities of highly putrescible matter. The account is as follows :—

Rich manure.

It has been stated how little solid matter is conveyed in this stream; nowhere in appearance is it as muddy as the Thames between the bridges, and yet much of the land irrigated by it becomes so rich that the surface is pared off every few years, not, as erroneously stated by some writers on the subject, in order to preserve the level of the lands for irrigation, but to obtain the vegetable matter which becomes in time too luxuriant in growth, as material for manure for other lands, for which it is highly prized. (*Prelim. Report S. of T. C.*, pp. 40, 41.)

Advantage of irrigation in winter.

It is calculated that to each acre is applied the liquid refuse of about forty persons; "but it must be observed that much of the water is used over and over again successively on lands at lower levels." So far from being a disadvantage in winter, we find that "the Vettabbia possesses also the valuable peculiarity of protecting from frost the meadows it irrigates, owing to the high temperature it receives in its passage under the town." (*First Report H. of T. C.*, vol. ii. p. 405.)

The expense of forming a meadow for irrigation appears to vary from about £8 or £10 to upwards of £40 an acre, according to the original character of the surface. The water is turned on for from six to ten hours once a week throughout the summer months, but a certain portion of the meadows are irrigated constantly throughout the winter, and are then called "Marcite." (*Prelim. Report S. of T. C.*, p. 41.)

No other manure necessary.

A good deal of land around Milan is irrigated with water containing no sewage, and on this land a considerable quantity of manure has to be used; while on the land irrigated with sewage even the manure of the cattle that are fed on its produce is used elsewhere. "To obtain the same produce from such lands" without irrigation would require manure worth "about £4 : 8s. per acre per annum."

Some of the meadows irrigated by the sewerage water of Milan yield a net rent of £21 per *tornatura* (a measure of 10,000 square metres, equal to about 2½ acres), besides a land-tax of 61 francs 10 cents, the expenses of administration, repairs of buildings, and so forth. These meadows are mowed in November, January, March, and April for stable-feeding; in June, July, and August they yield three crops of hay for the winter; and in September they furnish an abundant pasture for the cattle till the beginning of the winter irrigation. (*First Report H. of T. C.*, vol. ii. p. 406.) Rent. Crops.

The deputation appointed by the Sewage of Towns Commissioners considered themselves justified in stating that

The experience of the irrigations around Milan adds a striking additional proof to those already obtained of the great value to agriculture of a command of pure water alone, and of the immense increase of that value obtained by the addition of sewage combined with the higher temperature derived by the liquid in its passage through a town. (*Prelim. Report*, p. 44.) Value of water; but especially of sewage water.

Near Edinburgh, sewage irrigation has been going on for the last 200 years, according to the evidence of Mr. Christie-Miller, the proprietor of Craigentinny meadows, given before Dr. Brady's Committee. The quantities of sewage supplied to those meadows are enormous; thus in some parts it is applied at the rate of the refuse of 350 people per acre, the quantity being

Often as much as ten or fifteen thousand tons per acre during the growing season, besides an indefinite quantity during winter. . . . The stream flows on in almost undiminished foulness to the meadows lower down. . . . It is plain that an enormous quantity is applied, much beyond the needs of the largest possible crop of grass. (*First Report R. P. C.*, vol. i. p. 75.) Too much applied at Craigentinny meadows.

The proprietor, on the contrary, holds the opinion that the more sewage is supplied the richer is the crop. He says:—

I do not suppose that any tenant ever complained of having too much water put upon his lot . . . they have frequently complained of their not having enough, but we never had a complaint from a tenant that the waterman gave him too much. No complaint of too much.

The increase in the value of the land is very remarkable. Mr. James Smith, in his Report to the Health of Towns Commissioners (1845) on the Application of Sewer Water for Agricultural Purposes, says (*Second Report H. of T. C.*, vol. ii. p. 174) :—

Increase of value of land.

The practical result of this application of sewer water is that land which let formerly at from 40s. to £6 per Scotch acre is now let annually at from £30 to £40, and that poor sandy land on the sea-shore, which might be worth 2s. 6d. per acre, lets at an annual rent of from £15 to £20. . . . The average value of the land, irrespective of the sewer-water application, may be taken at £3 per imperial acre, and the average rent of the irrigated land at £30, making a difference of £27 ; but £2 may be deducted as the cost of management, leaving £25 per acre of clear annual income due to the sewer water.

During the past year the highest price attained was £41 : 17 : 6 per acre,* and from that down to £19 an acre has been realised. The Italian rye-grass on the same farm has varied in price from £32 an acre for the first year's cuttings, to £25 an acre for the second year's cuttings. (*First Report R. P. C.*, 1868, vol. i. p. 75.)

At another farm, where eight acres are supplied with about 3000 tons per acre annually, "a quantity which, at 1d. per ton, if ordinary sewage be taken to be worth so much, many ordinary agricultural crops would easily repay," the Italian rye-grass grown on them has been sold for from £25 to £36 an acre; "prices equal to those obtained at Lochend, where four times the quantity of sewage is applied. It would seem, therefore, that the enormous surplusage of foul water used at the latter place fails to be of any agricultural service." The summer's grass of the lower Craigentinny meadows

Equal crops with less sewage.

Is sold by auction to the Leith and Edinburgh cow-keepers every spring, and the maximum value reached last year was £36 : 15s. per statute acre. The quantity of grass for which such prices are obtained is believed to vary from 50 to 70 tons per acre. And as the means are perfected of distributing the sewage more evenly, and as the subsoil drainage of the land improves, the quantity and price are both increas-

* That is to say, that the receipt from a certain quarter of an acre was at this high rate.

ing year by year. No exhaustion is apparent anywhere. The sewage brings down more than the plants require of every necessary constituent of their food, so that even the poor sea-sand is as fertile as the rest, and the land is getting richer year by year, notwithstanding the enormous crops it yields. Taking the average price of the whole 240 acres to be £24 an acre, we have a total annual produce of £5760 a year extracted by the land and grass from the drainage of 80,000 people, or 1s. 5d. from each person annually—certainly not a halfpenny a ton, over the enormous quantity of sewage which is here applied. But the area is not sufficient to take up the whole of the filth brought down by the water. A much larger extent of crop could be obtained from the use of it, if there were any land convenient on which it could be applied, or if there were a sufficient demand for the produce of it." (*First Report R. P. C.*, 1868, vol. i. p. 75.)

Results on the whole.

That the results are not as satisfactory to the town as they should be, is seen from the fact that the receipts are £7000, while the cost of cleansing the town is £13,000; but it is better than quite wasting the sewage, as the cost of cleansing the city would be the same.

Results not satisfactory.

The Earl of Essex, who has applied the Watford sewage for irrigation, gave evidence before Dr. Brady's Committee that the increased value of land per acre, after deducting the price of the sewage, was £2 : 7 : 6 clear. It exceeded the rent of the ground. He considers that 60,000 tons are sufficient for 50 acres of land, and he finds that it is stored up as it were in the soil: "Put it on when you like, it remains in the soil till it is wanted by the plants." Four or five crops of rye-grass are produced in the season, and "I can fatten nearly two bullocks to the acre, besides seven or eight horses, and as many pigs as I have room for." On thirty-five acres of meadow grass 600 tons an acre were applied, and the result was an extraordinary crop, such as he "never saw before using the sewage." Wheat was also grown, and it was found to increase in value, both in straw and corn; it will thrive very well after Italian rye-grass:

Experience of the Earl of Essex.

Very valuable results.

134 tons of sewage were applied to each of two acres of wheat, and from each acre a value of £3 : 1 : 6 over and above that of the produce of any other acre in the field was produced, or 5½d. for each ton of sewage applied. The general results of this farm show that at three farthings a ton it will pay very well to irrigate with sewage, and, at a halfpenny a ton, uncommonly well; but that it would not be certainly profitable unless the sewage was got under a penny a ton.

Carlisle sewage farm.

Carlisle was the only town which informed the British Association Committee of 1870 that it had no present or prospective difficulty with regard to the treatment and utilisation of its refuse matters; but we found that only a part of the sewage was utilised by irrigation, the greater part being allowed to flow into the river; the following account must therefore be taken with this limitation.

Deodorisation by carbolic acid,

The evidence given before Dr. Brady's Committee shows that the sewage (? part of it) is pumped up from the main sewer (which really goes into the River Eden) on to some land, being mixed as it passes the pump with a small stream containing 1 per cent of carbolic acid, viz. 1 gallon of carbolic acid, 100 gallons of water, and 5 lbs. of lime. It is stated that after this admixture it is perfectly inodorous. It is supplied to the land at the rate of about 4000 tons per acre per annum, by means of iron pipes, which can be shifted about. There is no disagreeable smell. The crops are stated not to be so forward as those at Edinburgh, the reason assigned being, either that not enough sewage is put on the land (?), or that the carbolic acid "checks its immediate usefulness as a manure." This last is a reasonable supposition; it is

perhaps a disadvantage.

certainly very likely that a little too much carbolic acid would have that effect.

The Rivers Pollution Commissioners found that the whole of the sewage was absorbed by the sandy soil, so that there was, "properly speaking, no effluent water;" and so, as there was no drain outlet, the result of the purification effected by the land could not be easily shown. Nevertheless, the water taken from a hole 3 feet deep, dug in an irrigated meadow, was certainly sufficiently pure.

No effluent water.

The sewage of Malvern is utilised on a farm which was originally waste land covered with gorse: large crops have been got from it; the cattle prefer the grass which has been sewaged; the milk and butter are excellent; sheep thrive well.

Malvern sewage farm.

The cost of the preparation of this farm was, for 147 acres: drainage, £1000 (£600 for labour and £400 for tiles), and £3 per acre for fitting the surface of the land. (*Mr. M'Cann's evidence: Dr. Brady's Committee,* 1862.)

At Warwick the sewage is received into a tank at some distance from the town, from which it is pumped through iron pipes up to the highest point of a clay land farm about three-quarters of a mile distant. It is not received in a tank at the farm, but simply issues from the pipe at the highest point, and flows down through open carriers into the fields. It is stopped at intervals by the workmen, and caused to flow over the land. The sewage is here very dilute, and, as the land is a stiff clay, we were not surprised to find that the part which was at the time being flooded was almost a swamp, and we were told by the workmen that the difficulty of managing a large amount on this very unfavourable soil was, in winter, very con-

Clay farm at Warwick.

Effluent water purified.

siderable. But still we saw the effluent water flowing off at the foot of the fields in a clear stream, which, at its junction with the river some distance lower down, was as bright and limpid and free from any offence whatever as a stream could be. The analysis of this water by the Rivers Pollution Commissioners shows that the purification undergone by it is exceedingly satisfactory, especially when allowance is made, as it ought to be, for the concentration which the liquid undergoes by evaporation; although it must have been effected almost, if not entirely, by the action of the vegetation itself and of the surface of the soil, for evidently very little of it penetrated to any depth. Although this farm has perhaps as great disadvantages for the application of sewage water as a farm can have —namely, a stiff clay soil, a large quantity (10,000 tons per acre annually) of very dilute sewage (con-

Disadvantages of locality.

taining only 66·9 parts per 100,000 of total solid matters in solution), which, moreover, has to be all pumped to a distance of three-quarters of a mile from the outfall works,—"Nevertheless, the nuisance is sufficiently abated, and large crops of Italian rye-grass have been obtained, for which a ready sale at

Fine crops.

10s. and 12s. a ton, upon the ground, has latterly been obtained." We found that in that year (1870) it had been sold at £1 per ton, and the demand for it was greater than the supply. We also saw some root crops doing very well, some of which had been recently transplanted; and, what is more important

Example followed at Leamington.

perhaps to notice, the example set here was being followed by the neighbouring town of Leamington (where the "A B C" process had been for some time at work), and irrigation works were being constructed for that town, to supply a farm two and a quarter miles off with the sewage, which would have to be pumped all the distance.

At the Beddington meadows, near Croydon, the drainage of from thirty to forty thousand people has since 1863 been disposed of upon 260 acres of land. In the Ninth Report of the Medical Officer of the Privy Council it is stated with regard to this farm, that

The sewage after passing over the land contains just one grain of total impurity more than the water of the Croydon Water Works—22 and 23 grains to the gallon. Here the soil is porous gravel. At a second outfall, at Thornton Heath, 250,000 gallons daily are used, on 20 acres of land where grass and market produce are grown, and for most crops it is found to give remarkably favourable results. Here again the soil is gravel. At a third outfall, in Beckenham parish, 37 acres of stiff clay soil are irrigated, and the largest and healthiest crops of all to which the sewage is applied are got from this clay soil, a circumstance that was not expected, while the purity of the effluent water is almost absolute. A fourth outfall goes into the Metropolitan sewers. (*Loc. cit.*, Appendix, p. 101.)

Purity of effluent water at Croydon.

Especially good results on clay.

"Very heavy crops of Italian rye-grass have been grown here." (*First Report R. P. C.*, 1868, vol. i. p. 87.)

As much as 14 to 16 tons per acre are cut early in the month of May, and four or five cuttings a year are obtained, averaging from 8 to 10 tons each per acre. Mr. Marriage has also successfully used dressings of sewage in the cultivation of mangold wurzel; and when wheat has been grown after sewaged grass, he has irrigated the field with advantage even so late as the month of July, when the crop has appeared to be flagging and apparently suffering during a drought.

Crops of grass; mangold wurzel; wheat.

Here, too, the results of the purification of the effluent water are, as stated in the Public Health Report above referred to, and also by the Rivers Pollution Commissioners, exceedingly favourable even in the winter; it "was satisfactorily cleansed, and contained but mere traces of suspended matters." Except on one occasion during the whole year of

Great purity of effluent water.

1869, organic matters were present in the water "in proportions considerably below those necessary to render the effluent water an offensive addition to a stream at any season of the year." During a seven nights' continued frost, however, "the purification became markedly impaired." It appears "that the cleansing of sewage is, in the absence of actual frost, less dependent upon season than upon the quality of the sewage itself." As an instance of the utilisation of exceedingly strong sewage by irrigation, we may take the case of Banbury, where the sewers, which were laid in 1854-56, were made to have their outfall into settling tanks and filters, and the solid part, thus separated from the sewage, being mixed with street-sweepings and ashes, was sold for manure, while the liquid portion was allowed to escape into the Cherwell. This liquid is now pumped up to the highest point of a farm of 136 acres, which has been leased for twenty-one years at the rate of £4 : 10s. an acre, while the solid part which settles in the tanks is still disposed of in the same manner as formerly. The soil is for the most part a stiff clay, and much of the farm is old grass land which is not specially laid out for irrigation. These facts, and the strength of the sewage—which contained on 17th October 1868 no less than 111·5 parts of total solid matters in solution, of which nearly 14 parts were total combined nitrogen—make it not astonishing that the purification of the effluent water is not as complete as it is in some other cases; still, the results attained "are by no means unsatisfactory; and they are improving, both as regards the cleanness of the effluent water and the returns from the use of it."

Filtration at Banbury

Sewage farm.

Disadvantages.

Strength of sewage.

The accounts given of the produce of the land are satisfactory, and it is believed that the farm will soon repay rent and costs and loan ·

Produce satisfactory.

so that the nuisance hitherto created by the town will be ultimately abated without any serious permanent charge upon the inhabitants." (*First Report R. P. C.*, 1868, vol. i. p. 81.)

Worthing is another instance of a town where the sewage has been for some time utilised by irrigation. Formerly it was allowed to gravitate into the sea, fouling in its way a stream to the east of the town; now it runs into a tank, and is thence pumped up on to about 100 acres of land, although it appears that the night sewage is allowed to flow away. In 1866, Dr. Buchanan stated (*Ninth Report M. O. P. C.*, Appendix, p. 196, foot-note) that these irrigation works "appear to be to the completest extent satisfactory, both in their agricultural and financial results;" and from the account of the Solicitor to the Company it appears that the profits for the year 1869 amounted to £761 : 18s.; the receipts having been £1807 : 4 : 9, and the expenses £1045 : 6 : 9. But it must be noted that these expenses were abnormally increased by the "sum of £51 : 13 : 11 for a 'Level' rate made for the protection of various lands from the encroachments of the sea, which is a special and not an ordinary parochial rate," and by some other sums also. This farm consists of about 96 acres, of which about 83 receive the sewage of 7600 people, the daily volume being about 480,000 gallons (of which 130,000 gallons are spring or surface water). This shows at least a *net profit*, all expenses being paid, of 2s. per head of the population. The farm is very favourably situated, the soil being a good free loam, and the natural slopes convenient for the distribution of the sewage. The whole result is a decided success, although the sewage is very weak.

Satisfactory results at Worthing.

Profit per head of population.

Many other instances might be given of the application of sewage of towns in this way, in all cases abating entirely the nuisance of the pollution of the rivers, and, in several instances, already more than paying the expenditures. Thus, at Norwood the profit in 1869 was £148 : 5 : 9, the area under irrigation being 30 acres, from which the Croydon Board of Health obtained "a revenue of £22 per acre during nine months of 1868, and £25 per acre in 1869, which, spread over the population to whose drainage it is due, amounts to about 3s. 9d. per head per annum." At Aldershot farm it appears that the land is let to neighbouring cow-keepers at £20 an acre: "Supposing 40 acres here to yield £20 an acre, and other 40 acres to owe one-half of their crops, or £10 an acre, to the winter sewaging, we have here a return of £1200 from the waste of 7000 adults, or 3s. 4d. per head per annum." The sewage of Woking Invalid Prison has been applied to some very poor sandy soil, so very porous that a dressing of 40 tons of sewage, poured on in three-quarters of an hour at the head of a quarter-acre plot, is almost all absorbed before it reaches the foot of the plot. (*First Report R. P. C.*, 1868, vol. i. pp. 85, 78, 89.)

Profit at Norwood; at Aldershot.

Result at Woking.

The four plots of one acre were sown with Italian rye-grass in March, and three crops, averaging more than 12 tons each, were cut during the following summer, the plant having been repeatedly sewaged during the intervals. . . . On plots of similar soil, the heaviest and most luxuriant growth of savoys, kale, and cabbage has taken place."

Peat may be cultivated.

It appears, too, that peat when sewaged yields as abundant crops as anything else. It will be an immense advantage if peat bogs can thus be converted into fruitful fields. In all cases the value of the land has been most remarkably increased; it may be converted from perfectly worthless land, certainly not worth half-a-crown an acre, to land "worth £30 an acre to cow-feeders."

At Colney Hatch Lunatic Asylum, the sewage of 2000 individuals (120,000 gallons a day), is utilised on 70 acres of land, very good crops being produced; two dressings of 250 to 260 tons each are applied.

The sewage is received into a tank, and a deposit forms which is removed twice a year.

Expenses at Colney Hatch.

The plant cost £800, say £40 a year: the eight-horse engine, boiler, and pumps cost £4 a year for repairs; and the working expenses are 10s. 6d. a day (viz. coals 3s., two men 5s., and interest on capital 2s. 6d. = 10s. 6d.)

The sewage is not well managed, as half of it gets away unused. (*Dr. Brady's Committee.*)

Lodge farm, Barking.

The results obtained at the Lodge farm, Barking, are very instructive. In 1868 and 1869 experiments were tried with wheat, winter oats, rye, and cabbages. In 1868, wheat was sown on a slope of shingle; part was left unsewaged, and yielded 3 quarters 5 bushels with 3 loads of straw to the acre; part received two dressings of sewage (450 or 500 tons in all) and yielded 5 quarters 3 bushels with 4½ loads of straw to the acre. The winter oats, with three dressings of about 500 tons per acre in all, yielded 8 quarters of corn with 3 loads of straw per acre. The rye, with two dressings of 450 to 500 tons in all per acre, was thrashed in the field in July, and yielded 6 quarters with 3 loads of straw. The season of 1869, which was a less favourable one, still produced excellent results:—

Cereals: great success.

> The wheat has yielded 4 quarters per acre, the winter oats no less than 11 quarters per acre; the barley ripening unkindly only 4½ quarters per acre; but it must be remembered in all these cases, that the field, naturally a poor gravelly soil, was then yielding its third successive grain crop.

It should be stated that at this farm all kinds of crops have been grown. We have a list before us of no less than *thirty-eight different vegetables* which have all flourished upon it, beginning with cereals—including maize—passing through various forms of grass, pulse, greens, root crops of all sorts, potatoes, salad plants, and fruit in the shape of strawberries, raspberries, currants, and gooseberries.

Great variety of crops.

Return per head.

The Lodge farm experience, confining it to its growth of grass, may be said to represent a return of 5s. annually from every individual contributing to the sewage used upon it. Supposing the water supply to be over 30 gallons a head, each person will make 50 tons of sewage annually, corresponding to the production of 10 cwt. of grass worth 10s. a ton. (*First Report R. P. C.*, 1868, vol. i. p. 77.)

Irrigation at Cheltenham.

We have already mentioned that Bird's process has been abandoned at Cheltenham in favour of irrigation (see page 325). At this town the Commissioners have bought a farm of 131 acres, situated at a considerable distance from the town and below it, so that the sewage is delivered on to it by gravitation. The sewage is received into two tanks, the one near the lower part of the town and some three miles from the farm; the other at Hatherley, on the outskirts of the upper part of the town, and about 1½ mile from the farm; at these spots it formerly passed into the two small streams, the Chelt and the Hatherley brook (which discharge separately into the Severn), rendering them foul nuisances. Now, after depositing the greater part of the suspended matters in the tanks, which are constructed with several compartments (the sewage passing from one to the other, either over weirs, or from below upwards through rough filter-beds, so that the floating matters are stopped as well as the heavier suspended matters), the sewage passes onwards through two impervious pipe sewers to the

Tanks.

farm; the longer of these, the one from the Chelt tank, is 15,400 feet long, and has a fall of 25 feet, the average fall being 8 feet in a mile, although at one place the fall is only 1 in 1693; while that from the Hatherley tank is only 8400 feet long, and has a fall of 10 feet. Outfall sewers.

The sewers are well laid, and no deposit ever takes place in them; manholes are placed along them at such distances that a candle let down through one can be seen from the next, so that the sewers can at any time be easily examined from end to end. A great deal of surface water gets into the sewers, but means are being taken to separate this as far as possible.

The surface of the farm has for the most part a good natural inclination, and the soil is generally a stiffish clay; it was already laid out in ridges and furrows, so that it was suitably arranged for running the small carriers along the summits of the ridges; the land is almost all old pasturage, only a few acres having been sown with Italian rye-grass. With regard to the question of irrigating old meadow land with sewage, it must be remarked that near to the Chelt tank there are two meadows which have been irrigated for the last five years, and which are now in excellent condition; cattle are grazed on them and thrive remarkably well, and the only complaint that the farmer has to make is that he cannot have sewage on all his meadows. Old pasture land.

The farm is obviously too small for the purification of the sewage of so large a district, including as it does from 45,000 to 50,000 inhabitants, but a great deal of land is available along the course of the sewers, and the farmers are only too glad to prepare their land to receive the sewage and to pay for the privilege of having it. The purification is effected in great measure Farmers appreciate sewage.

by surface action, but it is very thorough, and the pollution of the brooks and the nuisance caused thereby have been stopped.

Costs.

The cost of establishing the farm was £18,000, of which £10,500 were spent in the purchase of the 131 acres of land, and £7500 in the construction of the outfall sewers and in the laying out of the land. The previous value of the land was from £2 : 10s. to £3 per acre at the outside; in the year 1870 it let on an average at £7 : 5s. per acre, the highest price realised being £8 : 13s. per acre for a lot of 24 acres, and the lowest £5 : 18s. per acre. "The total of the letting was £863 : 16 : 6 for the year, exclusive of the value of the piece of land kept by the surveyor for experiments." To this must be added the amount received for the sewage supplied to other farms, and also for the manure made by mixing the deposit in the tanks with town ashes and street sweepings, for which from £200 to £300 is obtained yearly, so that it appears that the Commissioners had in the first year gained enough to pay the interest on their loan and a moiety of the capital expended in permanent works (outfall sewers, etc.)

Receipts.

Conditions of rental.

The land was let under the following conditions: the tenants to be allowed either to graze or mow the land; the sewage to be applied *at the discretion of the surveyor;* the right of underletting not conceded; and a tenant desiring to erect any building on the land to be allowed to make arrangements for the removal thereof on the expiration of his tenancy.

Alleged pollution of wells.

We find that there was at one time a complaint made that certain wells had been poisoned by filtration into them of sewage water from the farm; on investigation the following was found to be the state of things. At one house where the well was com-

Real causes.

plained of, "the ditch is actually polluted with the soakage from the privy, and also receives the slops and liquid drainage from the house, so that it is quite impure and offensive; and this ditch is not very many yards from the well in question. . . . The other house . . . also drains into the ditch to a considerable extent, and, as I have for a very long time noticed, it is thus at certain times rendered very foul and impure" (*Surveyor's Report*). The facts speak for themselves.

On visiting this farm in the autumn, and again during the coldest week of the severe winter of 1870-71 we found no nuisance on either occasion, but, on the contrary, the brooks were clear streams instead of open sewers disseminating foul effluvia all around, as they formerly were. On account of the stiffness of the soil the water does not percolate easily, but it does not remain long enough on the surface to become stagnant, and the land soon regains its accustomed firmness and dryness. During the winter there appeared to be no great difficulty in managing the irrigation, but the ice in the small carriers had to be broken to allow of the free passage of the sewage along them.

Purification of brooks.

An account of sewage irrigation as carried out at Breton's farm, near Romford, is given in the Report of the British Association Sewage Committee for 1869-70. (See *B. A. Report*, 1870, p. 71.)

Breton's farm.

From it we find that the agricultural results with almost every kind of crop were very encouraging, even when the comparative advantage accorded to irrigation by the extreme dryness of the season is allowed for, while the purification of the sewage was exceedingly satisfactory, and indeed surpassed anything of the sort that we have yet seen.

Composition of the soil.

The analyses given of the soil show it to have been a very poor one, 31·65 per cent of it consisting of stones too large to pass through holes of a sieve which were 3·88 millimetres in diameter, while of the 66·43 per cent of soil which passed through the sieve (the rest consisted of roots, etc. and moisture lost at 100° C.), no less than 60·70 parts were insoluble in strong hydrochloric acid, the remainder consisting chiefly of ferric oxide, alumina, and lime, with traces of potash, soda, phosphoric acid, etc., while the loss on ignition was only 1·69 parts.

Comparison of sewage and effluent water.

From the analyses of the sewage as pumped on to the land, and of the effluent water, it appears that the total amount of solid matters in solution is not much altered by the process, that the suspended matters are reduced to an almost inappreciable quantity, that the ammonia is reduced from 3 or 4 parts to quantities varying from 0·046 to inappreciable traces in the 100,000 parts; and the albuminoid ammonia from 0·14 or 0·2 part to from 0·031 to 0·056 part in the 100,000 parts, while instead of these, nitrates and nitrites which are not found in the sewage appear in the effluent water to the extent of from 1·5 to 2·3 parts per 100,000.

The sewage from the town is really stronger than the figures above given would indicate, but the sewage pumped on to the land contained a large quantity of effluent water from the land, which was returned to the tank to dilute the sewage.

Produce and prices.

The produce of the farm has been especially fine, and the prices obtained for it very high, but for these we must refer to the Report from which we have quoted; it is sufficient here to say that it is finally proved "that sewage in its liquid state can be practically applied to apparently every kind of crop." One especially important observation is recorded :—

In Plot N, bed 1 (0·252 of an acre) was sown on 27th April with a new kind of American oats, which were cut on 22d August, and yielded 28 bushels, equal to 14 quarters, per acre. At the beginning of June this crop was seriously damaged, and in danger of being destroyed, by the ravages of the *Oscinis vastator*, one of the smallest but most destructive of those "grubs" and "wireworms" which at times cause such injury to cereal crops in this country. The remedial effects of sewage irrigation under similar circumstances having been previously observed elsewhere, two heavy dressings of sewage were applied to this bed during two successive days, the result being that the grubs were entirely destroyed, and the greater part of the crop was saved. It is proposed to conduct some experiments to ascertain whether this result could be accomplished by the use of pure water, or whether, with the physical effects of immersion, sewage applied in this way combines the action of some agent or agents which act as a specific poison to organisms of that type. (*Loc. cit.*, p. 65.)

Destruction of wire-worms by sewage.

As to the quantity of sewage applied to the land, it appears that in all probability "400 tons per acre is the largest quantity that has ever been applied in any one dressing; and if we assume that the first dressing all over was at the rate of 400 tons per acre, that the second dressing was at the rate of 200, and that the subsequent dressings were at the rate of 100, we shall not be far from the truth" (p. 69).

Quantity of sewage applied.

The drought in the summer of 1870 was so severe that even the irrigated lands did not get as much water as they required, and so it is not to be wondered that the contrast between the crops they yielded and those yielded by other lands was more marked than ever :—

A small field of between three and four acres in the adjoining farm was sown with peas for picking green. These the farmer tried to sell on the ground for £8 an acre ; but he was unable to sell them at all, and at last left them to ripen. They still remain unsold, and are estimated to be worth from £5 to £6 an acre, while the straw was so stunted that there were not two loads from the whole area" (p. 69).

Comparison with other farms.

On Breton's farm four beds in Plot B, "equal to

1·96 acre, were sown in the first week in April with 'Champion' peas for eating green, which were sold in July for £30, the buyer picking them and leaving the straw" (p. 63).

In the next field beyond the peas (farmed by one of the best agriculturists in the county, a man of superior education and agricultural knowledge, who has farmed the same land for years past with immense care, having planted small hedges here and there to give shelter and break the wind, and having grubbed up the old hedges, and having further collected the stones off the surface of the land, and who applies farmyard manure, guano, bones, etc., with both liberality and judgment) were sown onions, and these onions the farmer said that he would gladly sell for one-fifth of their cost.

Prices for onions.

Let this be compared with the prices realised for the beds of onions on Breton's farm, viz. £36 per measured acre for two of the beds, and £46 per acre for another.

Again, upon the small meadow at Breton's marked U, comprising altogether, after deducting ponds, etc., only $5\frac{1}{4}$ acres that can actually be mowed, the two crops of hay already got in amount to 9 loads ($3\frac{3}{4}$ and $5\frac{1}{4}$ respectively); and a third is growing, which with care and energy, and the assistance of a large barn, may easily be got in in the present month (September), and is estimated as equal to the first, making a total of $12\frac{3}{4}$ loads in one season from $5\frac{1}{4}$ acres. The tenant of Breton's has a large meadow, about three miles nearer London, sloping down to a brook shaded by trees, and which ought to suffer less than most from drought; yet off an available area for mowing of 27 acres he was only able to get four loads of hay, and there is scarcely any aftermath at all. In potatoes and carrots the figures run in about the same proportion between the sewaged and the unsewaged ground, while of green crops without sewage there were simply none (p. 70).

Failures from want of water.

Lodge farm.

From a paper read by Mr. Henry John Morgan, before the Institution of Surveyors, on 27th March 1871, we find that the results obtained at the Lodge farm, Barking, have been very satisfactory in so far as the obtaining of large and valuable crops goes, but, as the writer says, "it would not be safe to base calculations of what price a farmer could usually afford to pay for the sewage upon the amounts which have been realised by us at a time when drought had deprived the market gardeners round London of their crops."

The year 1870, although a very favourable one for contrasting irrigation with other methods of manuring, was not so for obtaining the largest possible crops, as even with the aid of irrigation enough water could hardly be got on to the land: in other words, a less dry season would certainly show larger absolute, though smaller comparative results, in favour of irrigation. Influence of drought on comparative results.

The "Report on the Measures adopted for Sanitary Improvements in India, from June 1869 to June 1870," contains an abstract of Captain Tulloch's report on the Madras sewage farm, of which report it is stated (p. 25) that it enters "fully into the economic bearings of the experiment, and, viewed in this light, there seems little doubt of its proving a great financial success." From this report it appears that a great variety of crops have been successfully grown, while even during the monsoon the difficulty of dealing with the excess of water does not seem to be at all insurmountable. Madras sewage farm.

The Leicester County Lunatic Asylum has afforded another instance of successful sewage irrigation, and an especially interesting one, as accounts have been kept for some years, and the profits realised are known exactly; the results have been described and compared with those obtained from the "A B C" process at Leicester, by Mr. Henry Waugh, C.E., in a pamphlet, "On the Disposal of Sewage in Towns." Leicester County Asylum.

It appears that the sewage of about 500 persons, amounting to about 11,500 gallons a day, "flows continuously, day and night, over a few acres of ground cultivated by the patients of the Asylum."

Profits from irrigation.

The profits have risen with the number of patients, and now, after payment of rent, taxes, labour, and interest of money, "the average net profit at present amounts to about £550 per annum" (p. 12).

No injury to health.

The earth over which the sewage has been run for eleven years has no unpleasant smell or appearance. It was tried under all circumstances, from quite dry to recently irrigated; and in no instance was there any unpleasant odour. The gardener, his labourers, and the patients who work with them, enjoy excellent health; and, in fact, the general health of the Asylum is so good as to offer the best testimony to the absence of all danger from the experiment; and, let it be remembered, this is not a question of carrying the fluid sewage to a considerable distance before using it; the outfall of the drain and commencement of the distributing canals being within 50 yards of the main buildings of the Asylum."

General results.

Here then, the sewage has been purified, the effluent water being "pure, clean, and soft," there has been no detriment to health, and "the land has paid for this good treatment at the rate of £1 : 1s. per head per annum." We are informed that the value of the labour of the patients has been calculated and subtracted from the receipts, and we think that enough has been said to justify the statement made by Mr. Waugh:—

Every town of England has now in its own power the means of greatly reducing its local taxation, by converting what has always been a dangerous nuisance into a fruitful source of revenue; improving, at the same time, the health and comfort of the community (p. 20).

Sewage irrigation at Birmingham.

Birmingham has lately acquired 1200 acres of land at Saltley and Tyburn for the disposal of its sewage, which averages in dry weather 15,000,000 gallons daily. In the first place the sewage is treated with lime, this being not only necessary to precipitate the suspended matters and prevent clogging of the pores of the land, but absolutely essential to neutralise the free acids which the sewage of this manufacturing district contains, before allowing it to flow over the land.

As much as 25 parts of chlorine, partly, no doubt, in the form of free hydrochloric acid, are contained in 100,000 parts of the sewage. Milk of lime in the proportion of 13 grains to the gallon is allowed to flow into the main sewer about a quarter of a mile from the settling tanks on the farm. The sewage has a yellowish brown colour, which is not altered by the lime treatment, the effluent after precipitation being clear, but having the same colour. The iron salts present in the sewage undoubtedly aid precipitation after the introduction of lime. Arrived at the settling tanks, precipitation takes place, between 5 and 6 hours being necessary for deposition and for running off the liquid without disturbing the sediment. In windy weather, however, deposition takes longer.

Precipitation by lime.

The liquid sludge in the tanks, containing 90 per cent of moisture, is raised from a well in the floor of the tank by revolving buckets, driven by steam, into temporary wooden carriers, along which it flows on to the land. Here it parts with some of its moisture to the air, and is then dug into the soil, which is subsequently planted and cropped for one year and then steam ploughed and afterwards used as a filter bed. About 580 tons a day of sludge are produced, an acre of land a week being used for digging the sludge in. This acre is not again used for the same purpose for a period of 3 years. Altogether 156 acres are required for the disposal of the sludge. The heavier parts of the sludge in the settling tanks, consisting chiefly of road debris, are dug out by hand labour and disposed of as above.

Sludge dug into the land.

The effluent from the tanks is carried on to every part of the land by gravitation, through masonry carriers. The system employed is that of intermittent downward filtration, the land, which is light, loamy, The land under-drained.

and gravelly, being under-drained over its whole extent by drains of from 30 to 60 feet apart, and from 4 to 6 feet deep. About 900 acres are thus used for filtration. The permanent carriers are of masonry, the temporary carriers are grips in the land.

Crops of the farm.

All kinds of crops are grown on the farm, and, as there is a difficulty in disposing of all the produce, a large stock of cattle and sheep are kept and fattened, and large quantities of milk are sent to market. Fifty tons of mangold to the acre is an average quantity in favourable weather. Wheat and barley are not grown on the sewaged lands. Ensilage has been tried, but the results of the experiment are not yet determined.

At the time of our visit the effluent from the land, which flows into the river Tame, was bright, clear, and inodorous, in fact a purer water than that of the river into which it flows. The effluent contained 7·5 parts chlorine in 100,000 parts. The income from the farm for the year 1883 was £16,403.

Remarks.

Our observations lead us to the conclusion that the question of the disposal of the sewage of a large town has been satisfactorily solved in this instance, and that great credit is due to the corporation of Birmingham for the successful way in which they have grappled with the difficulties of the case.

ADOPTION OF SEWAGE IRRIGATION ABROAD.

In the First Report of the British Association Sewage Committee (p. 28), it is stated that in this country "in only 15 places out of the 96 where the water-carriage system of removing excretal refuse is adopted, either generally or partially, is the sewage applied for irrigating land." Since that time, 1869, many other towns in this country have adopted some form of treatment on land for the purification of their sewage, whilst abroad sewage irrigation has been tried in several instances with considerable success.

Among foreign opinions on the subject of sewage irrigation we may quote the following :—

Foreign opinions and results.

"The agricultural value of the sewage water now poured uselessly into the Baltic has been proved by an experiment made last year on a very small scale, by irrigating pure sea-sand with the water of one of the principal canals of Stralsund : the results corroborate the favourable reports received from England, rye-grass having been cut every month from 12 to 18 inches high ; Bokhara clover has also grown well on the irrigated sand." (*German Quarterly Review of Public Health.*)

The engineers to the municipality of Paris remark in their Report, in speaking of irrigation :

French Engineers' Report, 1870.

"The agricultural results are not to be doubted. We are on a gravelly soil which calls for the alluvium formed each day by the traffic and life of two millions of inhabitants. We enjoy a temperate climate invigorated by a radiant atmosphere, all is possible—grass, vegetables, flowers, and fruits ; and we have, for disposing of the produce, an unrivalled market, 'Les Halles' of Paris. It is therefore time to will and to act."

Recommendations to Prussian Government.

Professor Dunkelberg, of Wiesbaden, also holds the opinion that "the irrigation system can alone cover the expenses and deliver the manure in the simplest and most efficient manner for the farmer ;" and he recommends that a bill be passed by the North German Confederation to the effect that all sewage should be fully utilised in the irrigation of land, and no longer suffered to pollute any running water. Michel Lévy also gives in his unqualified adhesion to the irrigation system. He says (*Traité d'Hygiène*, tome ii. p. 433) :—

Michel Lévy's testimony.

All will go to the sewer, and, by the prolonged sewer ramified to a distance, on to the earth in its natural form. Excrement, urine, slops, residues of every kind, all this constitutes the richness of the liquid manure, carted (*charrié*) by the sewers ; it is useless to collect it in large tanks, to manipulate it, to transform it ; the spreading of it over the soil, directing it by inclined culverts upon the lands which have need of it, preserving the purity of the waters, of the streams, and of the rivers ; such is the end that more than one city has already reached, that London actively pursues, and that the force of circumstances will induce the administration of our capital to search after; but not without great expenditure, of which the repayment is sure.

Dumas's opinion.

Lastly, Dumas, when inspecting the Barking farm, expressed his opinion in these words—which, coming from the mouth of such a man, are worth volumes of unauthorised statements:—"*Oui, l'eau doit être la charrette de l'engrais.*"

Sewage of Paris.

A small portion of the sewage of Paris is utilised by irrigation on the plain of Gennevilliers near Asnières on the bank of the Seine. The sewage of Paris contains only a part of the solid excreta of the population, as cesspools are still in general use in the city, nevertheless it is rich in fertilising matters both in suspension and solution.

Sewage irrigation at Gennevilliers.

An account of the sewage farm at Gennevilliers and the results obtained are given in the Report of the Local Government Board Committee (Appendix, pp. 68-70), whose members visited the farm in 1875. We find from this report that the soil of the plain is well adapted for sewage utilisation, as it consists of a light open soil on a gravelly subsoil of considerable depth; and it, therefore, serves the purpose of a natural filter; about 400 acres are under irrigation. Very numerous allotments of land have been made, and are let on lease for terms varying from 3 to 15 years; the number of allottees who use the sewage increases every year, and the owners and occupiers are much pleased with the result. The prejudice which at first existed against the use of sewage as a manure, and against the produce grown by its aid, has died out.

Allotments of land.

The crops grown under sewage irrigation have been a perfect success; they comprised absinthe, artichokes, asparagus, beans, beet-root, cabbage, cardon, carrots, celery, chevril, chicory, cohl-rabi, cucumbers, leeks, melons, onions, parsnips, peppermint, potatoes, pumpkins, spinach, tomatoes, turnips, lucerne, clover, Italian rye-grass, mangolds, wheat, oats, and Indian corn. The market-garden produce yielded very abundant crops. The asparagus is grown in nursery-beds as plants, and afterwards sold to gardeners, who force it for use of consumers. The Indian corn was of exceedingly luxuriant growth, 9 to 10 feet high. The potatoes gave a very good crop; the sewage is applied to the land before planting potatoes, and not to the growing crop except in drought. The Italian rye-grass and lucerne yielded five cuttings for hay and two cuttings green for cattle feeding. It is found that the application of sewage to lucerne more than doubles the weight of the crop. A meadow of natural grass (principally cocksfoot) under sewage treatment, yielded three crops of hay in the year, and these realised £15 : 15s. per acre. Application of sewage to young fruit trees has also been very successful. The average yearly rainfall is 20 inches. The hot and dry plain of Gennevilliers is capable of absorbing a very large volume of sewage, especially in the summer season. It is found that the sewage does not readily freeze, and therefore can be applied continuously to the land. The available area of land at Gennevilliers is insufficient to receive the daily volume of the Paris sewage, and we were informed that it is in contemplation to extend the main conduit to St. Germain, and to irrigate the land lying on the edge of the forest, and also the forest itself if necessary.

Luxuriant crops.

Large volume of sewage could be absorbed.

The effluent water after percolating through the gravelly subsoil flows into the river Seine, and at the date of our visit it was clean, bright, and inodorous.

In Germany, Berlin, Breslau, and Dantzig now dispose of their sewage by irrigation on land, and the sewage farms have proved highly successful.

Sewage irrigation was not, however, adopted at Berlin until after experiments had been made with a large number of chemical processes. "All these experiments," says M. Durand-Claye, "led to the results everywhere obtained by such methods of treatment of sewage: clarification, but not purification; great expense and much difficulty."

Berlin experimented with chemical processes.

Irrigation was then tried on a small field of nearly 10 acres close to Berlin from July 1870 to March 1872. The result was a perfect success; abundant crops were obtained, and the effluent water was always found to be satisfactorily purified. These results, together with the experience obtained from abroad—and especially from England—decided the municipal-

Trial of irrigation.

ity to adopt irrigation as a means of purifying the whole of the sewage.

The following particulars as to the Berlin sewage farms are taken from the Report for 1884-85 of the Committee of Management of the Sewage Irrigation Work, for which we are indebted to Mr. A. Aird.

Population

The population of Berlin, from the recent census returns, is 1,300,000. The area at present sewered contains 14,641 houses. The ascertained average number of inmates per house is 60·62, so that the population at present contributing to the sewerage works is 887,537, or three-fifths of the entire population. The water supplied daily per head of the population is 14·4 gallons. The amount of sewage pumped daily per head of the population is 22 gallons; the difference representing rain and surface waters, and water used for municipal or manufacturing purposes.

Volume of sewage.

Altogether about 19½ million gallons of sewage require to be disposed of daily. The sewage varies considerably in composition at different parts of the year, and it is not unusual for it to arrive at the sewage farms in a putrid condition. The area of land already purchased by the municipality for irrigation purposes is 11,000 acres, of which nearly 71 per cent is levelled and under irrigation. This land is situated in different districts outside the city, but the larger portion lies to the north of the town. During the year March

Amount of land irrigated.

1884-85, 7792 acres of land were irrigated, and the average amount of sewage applied daily per acre was 2500 gallons nearly. Besides the land in possession of the municipality the sewage can be applied by arrangement at certain times on 420 acres of land belonging to private owners, and on 25,000 acres of meadow land, belonging to the "Nuthe" association.

Much of the work on the farms is done by the workhouse poor; the number so employed averaged, during the year, 1137; this arrangement is said to work very satisfactorily. Grass land is let out at from £3 to £4 per acre per annum; 621 acres are laid out as beds for beet culture, and this industry yields an annual profit of £2000. The municipality has gained many prizes for vegetables, etc., at the agricultural shows. About 700 head of cattle, and 860 sheep are kept on the farm, and a large number of horses. The tables of mortality and sickness on the farms show that no influence adverse to health can be attributed to sewage farming. The annual outlay on the farms is £83,134, whilst the income is £80,415, so that there is a deficit of about £2620 on the year 1884-85. The farms which have been under irrigation from the first, and are now in complete working order, are yielding profits. The effluent from the farms has never been in such a state as to give rise to any complaints. The effluent from the northern farms, which passes into the "Rummelsburger See," which is connected with the river Spree, just above the water-works intake, is so insignificant compared with the volume of water into which it passes, that no danger is apprehended to the water-supply.

Beet culture.

No influence adverse to health.

Effluents from the farms.

The municipality of Berlin has thus in the most public-spirited manner settled the question of the disposal of the sewage of that city, and we cannot conclude our description better than by quoting what M. Hobrecht, the engineer of these works, said to M. Durand-Claye. "The city of Berlin never refuses us the necessary money, when it is a question of health and of sanitary works!" An example which might well be followed by other cities.

City of Berlin an example.

Dantzig and Breslau as well as Berlin have established irrigation works for the treatment of their sewage. The sewerage and irrigation works of these three cities were visited in 1880 by Professor A. Durand-Claye of Paris, and described by him in *La Revue d'Hygiène*—January and February 1881.* From his account we find that the works at Dantzig were commenced in 1869 and completed in 1871, under the superintendence of Mr. Aird of Berlin, to whom also the sewage farm was leased for a period of thirty years. The dry weather sewage of the town amounts to nearly 3,000,000 gallons daily. During wet weather the quantity to be dealt with may reach 3,600,000 gallons daily. The sewage is pumped from the town—after being freed from its larger solid matters by a Latham's extractor—to the sewage farm through a pipe 22·6 inches in diameter, and 3175 yards in length. The vertical height through which the sewage is raised in its course to the farm is about 33 feet. The land used for irrigation is situated between the Vistula and the Baltic Sea, not quite two miles from Dantzig, and covers about 1235 acres. The surface is undulatory and the soil is a very permeable sand, containing, however, a good deal of iron, which gives the effluent water a yellowish tint. So permeable is the soil, and with such avidity does it absorb the sewage, that it has not been found necessary in any one year to irrigate more than one-third of the farm, and it has even been found desirable to irrigate portions of the farm with water from the river Motlau. The effluent from the farm is always limpid and odourless, although often coloured yellow by the iron in the soil. The conditions present, M. Durand-Claye observes, are very favourable to purification of the sewage, but much less so to its utilisation.

Dantzig.

Land used for irrigation.

Effluent.

* Les travaux d'Assainissement de Dantzig, Berlin, Breslau.

The irregularities of the surface necessitated much work in levelling and plotting, whilst the extreme porosity of the soil has prevented the application of sewage to many parts of the farm, which would be much benefited thereby. The violent winds tend to raise clouds of sand off the neighbouring dunes which choke the vegetation, and the climate is cold and bleak, severe frosts prevailing in winter. During the hardest frost, however, the sewage sinks beneath the surface coating of ice and snow, and filters through the soil without causing any injury to the plants or trouble to the contractor. The farm has been productive of excellent crops of grasses, roots, and cereals. The latter appear to thrive well on this very porous soil when treated with large doses of sewage. The value of the land has increased enormously. Formerly worth next to nothing, small portions are now let off by Mr. Aird for from 100 to 500 francs the acre. "It is a truly curious sight," says M. Durand-Claye, "to see, surrounded by irregular dunes of blowing sea-sand, vast spaces covered with a vigorous vegetation as a result of the application of sewage, and it is of much credit to the municipality of Dantzig, that, although the town is surrounded by rivers of large size, and lies within three miles of the sea, it has rejected the false and barbarous system of casting untreated sewage into sea or river." The sewage farm has had no adverse influence on the health of the neighbouring villages and garrisons of the fortress of Weichselmünde, and the death-rate in Dantzig itself since the completion of the sewerage and irrigation works, and the introduction of a better water-supply, has been reduced 21 per cent, viz. from 36·5 in 1869 to a mean of 28·5 from 1872 to 1879.

Climate cold and bleak.

Land increased enormously in value.

No ill effect on health.

Breslau, a town of 250,000 inhabitants, has carried

Breslau.

out, under the superintendence of Mr. Aird, sewerage and irrigation works on plans very similar to those adopted at Berlin and Dantzig. The sewage, after being filtered through coarse gravel, is pumped into a metal pipe 4000 yards in length, to the sewage farm on the banks of the Oder. The vertical height through which the sewage is raised is about 16 feet. The farm, which is about 1000 acres in extent, has been leased to Mr. Aird for a period of ten years. At the time of M. Durand-Claye's visit in 1880, the soil of the farm, which is very porous, was being prepared for the reception of the sewage. It was expected that 250 acres would be amply sufficient to purify all the sewage of the town for many years to come. The total cost of the irrigation and sewerage works is estimated at 2½ millions of francs.

Land being prepared for sewage.

M. Durand-Claye's conclusions from his visits to Dantzig, Berlin, and Breslau are worth quoting here:

In Germany it is now everywhere admitted without dispute that the sanitation of towns rests upon three principles: (1) The discharge of all the excretal matters into the sewers; (2) an abundant supply of water to the houses, and frequent flushing of the sewers; (3) the purification of the sewage by the soil and vegetation.

Sanitation of towns.

Pullman, a town of 8500 inhabitants, situated near Chicago, United States, is sewered on the separate system, on very similar lines to those adopted at Memphis. The town being situated on a gentle slope, the surface waters run down channels in the streets to their natural outlet in Lake Calumet. The town is entirely water-closeted, and rather more than half a million gallons of sewage are produced daily. The branch sewers are of small size—from 2·5 to 3·5

Pullman, U.S.A.

inches in diameter, and receive the water-closet sewage and house waste waters. They empty into a main sewer of cast iron, 19·5 inches in diameter, which discharges its contents into a reservoir. From here the sewage is pumped up about 26 feet on to the surface of a farm, situated about three miles from the town. This farm, which covers nearly 140 acres, has a surface soil of alluvial sand lying on a subsoil of clay, and is underdrained throughout its whole extent. The sewage farm.

The surface of the farm is laid out in ridges and furrows. The effluent from the farm is clear and inodorous, and flows into the Lake Calumet. The sewage invariably arrives at the farm in a fresh and undecomposed condition. Market garden and dairy produce in large quantities are the staple commodities of the farm, but sheep are also kept producing wool of first-class quality. About 10 acres of land are prepared as filtration beds to take the sewage at all times. The rest of the farm only has sewage applied to it when it will be of benefit to the crops. The farm has made a profit of over £1000 a year, not taking into account the expense of pumping, nor interest on the cost of the land and its preparation. The health of the employés on the farm, about forty in number, is exceptionally good. Pullman also is extremely healthy, the death-rate averaging only 7 per 1000 per annum, and malaria, which is the scourge of other towns in the vicinity, is unknown in Pullman. Filtration beds. Very low death-rate at Pullman.

From the Report of a Commission appointed to consider a general system of drainage for the valleys of the Mystic, Blackstone, and Charles Rivers, Massachusetts, United States, 1886, it appears that until now the disposal of sewage by irrigation on land has made but little way in America. This arises to a The disposal of the sewage of towns in America.

great extent from the fact that the rivers are much larger than in England, and the populations on their banks very much less dense. The pollution arising from turning crude sewage into rivers is consequently not very great, except in the case of streams which are much reduced in size in summer from prolonged drought. Clarification of sewage by chemicals is not now—and probably in the future—will be but little resorted to, owing partly to the great expense of chemicals, plant, and labour in the States, and partly to the cheapness of land in nearly all districts. Again there is but little demand for artificial fertilisers in the States, so that the sludge produced by chemical processes would be very generally an unsaleable product. Land, where needed, could generally be acquired on easy terms, and as there is comparatively but little inducement to cultivate the areas on which sewage is disposed of, purification of the sewage by filtration would be the first object in view, but the works might be arranged in such a manner that the sewage could be utilised for short periods in summer, when needed. But little trouble is anticipated from the severity of the winters in America; as it has been found at Pullman that irrigation has always proceeded there without interruption. During a visit paid to the farm in February 1885, by one of the Commissioners, although for five days previous the mercury had not risen to 0°Fahr., and had been as low as −25°, it was found that the sewage was going on to the land, but covered by a stratum of ice, from 1 to 8 inches thick. On breaking the ice and digging a hole in the ground below with a spade, the soil was seen to be unfrozen and perfectly open. As the weather moderated the sewage rapidly melted the ice above it.

Chemical methods not suitable.

Filtration through land.

Irrigation on land not interrupted by frost.

EXPERIMENTS ON VARIOUS CROPS.

The Sewage of Towns Commissioners instituted a series of important experiments to show the value of sewage and the amount of the crops that could be got from it by irrigation. From these they concluded—

That the most beneficial and most profitable method of disposing of sewage where circumstances will admit of this use of it, is by direct application in the liquid form to land; where such applications can only be conveniently effected near habitations, it may be desirable to employ some deodorising agent, but usually, if proper arrangements are made for conveying sewage on to the land, this expense need not be incurred. (*Second Report S. of T. C.* 1861, p. 40.) Conclusion, S. of T. C.

By the application of large quantities of dilute town sewage to permanent meadow land during the spring and summer months, there was obtained an average increase of about four tons of green grass, (which, owing to the lower proportion of dry substance in the sewaged grass, was equal to only about three-fourths of a ton of hay) for each thousand tons of sewage applied, until the amount of the latter approached the rate of about 9000 tons per acre per annum. The largest produce obtained was about 33 tons of green grass per acre. The period of the year over which an abundance of green food was available was, with the largest amounts of sewage, between five and six months. (*Report by Mr. Lawes, loc. cit.* p. 36.) Experiments of Mr. Lawes. Produce.

This grass was shown to be suitable for fattening oxen, especially if a little oilcake was given in addition. Milch cows give considerably more milk in proportion to the solid matter contained in their food when fed on sewaged than on unsewaged grass, though they give a less quantity in proportion to the quantity of fresh grass consumed. "Milk to the gross value of £32 per acre was obtained where the largest quantity of sewage was applied. The gross value of the milk from the increased produce of each thousand tons of sewage was between five and six pounds." Sewaged grass contains less dry substance than unsewaged grass, and a given weight makes less hay, but the dry substance of sewaged grass generally contains a higher Fattening oxen. Milch cows.

More nitrogenous matter in sewaged grass.

proportion of nitrogenous compounds than that of non-sewaged grass. (*Loc. cit.* p. 37.)

In the Third Report of the Commission (1865) the following results are recorded (pp. 72, 73):—

Early and late crops.

By the application of sewage to grass-land during the winter a very early cut or bite of green food may be obtained, but the amount of increased produce due to the winter application is comparatively small for the amount of sewage employed.

Poor soil as fertile as good one.

Increased amounts of produce;

The period during which an abundance of green food was available was extended considerably at the end as well as at the beginning of the season; and the more so the larger the quantity of sewage applied, almost up to the highest amount employed, viz. 9000 tons per acre. A poorer soil gave fully as much produce per acre, under the influence of liberal dressings of sewage, as the naturally much more fertile soil. While, from the average of three years, and from the two fields on which the experiments were conducted, the amount of produce obtained, without sewage, was about $9\frac{1}{4}$ tons of green grass per acre per annum, equal to about 3 tons of hay; with 3000, 6000, and 9000 tons of sewage per acre per annum the amounts were respectively about $22\frac{1}{4}$, $30\frac{1}{4}$, and $32\frac{1}{2}$ tons of green grass, equal respectively (reckoned according to the percentage of dry substance in each) about 5, $5\frac{3}{4}$, and $6\frac{1}{2}$ tons of hay.

not proportional to increased amount of sewage.

But the largest quantities obtained were as much as 35 tons of green grass in one field, and 37 tons in the other, equal respectively to 6 tons $12\frac{3}{4}$ cwt. and 7 tons 1 cwt. of hay. These crops were produced with 9000 tons of sewage per acre per annum. The increase in the crops was not proportional to the increased amount of sewage, for the increase per 1000 tons was, when 3000 tons were applied, about 5 tons of green grass; when 6000 tons were applied, 4 tons $2\frac{1}{2}$ cwt.; and when 9000 tons were applied, 3 tons $3\frac{1}{4}$ cwt. The results obtained with Italian rye-grass gave about the same increase of produce.

Fattening oxen; less return than with milch cows.

Fattening oxen consumed more sewaged than unsewaged grass to produce a given rate of increase; but, reckoned as dry solid substance, the amount consumed was less to produce the same result. It was found advisable to give oilcake in addition, and the money return was not nearly so favourable with fattening oxen as with milch cows. With regard to the weights of sewaged and unsewaged grass which produced a given quantity of milk, the results were the same as before, all of them showing that the dry solid substance contained in sewaged grass is more nourishing than that contained in unsewaged grass.

On the average, about six parts by weight of fresh grass yielded one part by weight of milk. By the aid of sewage, the time that an acre would keep a cow, and the amount of milk yielded from the produce of an acre, were increased between three and fourfold. (*Third Report S. of T. C.*, p. 74.)

Favourable food.

Sewage-grown Italian rye-grass was found to be more favourable for the production of milk than meadow grass (the result of only one experiment). From these experiments it is calculated that "with an application of about 5000 tons of sewage per acre per annum to meadow land, an average gross produce of not less than 1000 gallons of milk per acre per annum may be expected . . . an average gross return of from £30 to £35 per acre, in milk at 8d. per gallon, may be anticipated." With regard to the grass, it has been stated that the proportion of nitrogenous substances was greater in the sewaged than in the unsewaged grass. It was also found that this quantity was much higher in the solid matter of the grass grown towards the end of the season; and it would appear that the greater productiveness in milk and in increase of flesh, observed as the result of feeding with sewaged grass, depends more on the *quality* of these nitrogenous matters, and their ready assimilability, than on the actual percentage of them. The milk obtained was greater in quantity, when

Return from milk.

Quality of the nitrogenous matters in the grass.

Quantity and quality of the milk.

compared with the amount of dry solid substance in the grass, with the sewaged than with the unsewaged grass. It was, however, slightly less rich, but when some oilcake was given with the grass its richness was notably increased. An experiment was made on the effect of sewage irrigation upon oats: this showed that when only 135½ tons of sewage per acre were employed, "the gross value of the increased produce amounted to more than 5d. per ton of the sewage employed, or to about three times the market value of the constituents of the sewage, supposing them to have been extracted and dried; and in another experiment, in which 510 tons were applied per acre, the gross value of the increased produce amounted to about 1½d. per ton of the sewage employed" (*Loc. cit.* p. 78). These experiments were made under exceptional circumstances, with dry weather, a very productive season, and sewage of about double the strength of the London sewage. These results with oats, as well as those obtained by the Earl of Essex with wheat, show in both cases "a very high gross money return per ton of sewage employed." The general conclusions of these Commissioners are—that sewage should be applied, to obtain the highest value from it, "in small quantities per acre, and in dry weather;" that 5000 tons per acre applied to properly prepared grass land would produce the most profitable result; and that the effluent water would be sufficiently purified. That the above quantity would represent the sewage (including rainfall and so forth) from fifty individuals, so that "a population of three millions would require about 60,000 acres constantly under irrigation." That the greater proportion of sewage would have to

Experiment upon oats.

Excellent results.

High return.

Should be applied in small quantities per acre.

be used on grass land, because the expense of distributing it by means of piping and hose-and-jet to arable lands instead of by open carriers (as to grass land) would be too great to warrant the large employment of it in this way. We shall see that this method of distribution is not by any means necessary in the application of sewage to arable land any more than it is to grass land. The Commissioners concluded from their experiments "that the farmer would not pay three-farthings, and probably not a halfpenny per ton the year round, for sewage of the average strength of that of the metropolis (excluding storm-water), delivered on his land." It is pointed out by the Sewage Committee, 1862 (Dr. Brady's), that the reason that such an unfavourable monetary value was got by Mr. Lawes was, that the sewage was applied in a manner likely to cause waste, and in too large a quantity; and the case of Annerley schools was instanced, where 9d. a ton was got in value from the sewage, and where it was found that 1500 tons per annum, distributed by hose-and-jet (*i.e.* distributed carefully), produced a result equal to that from 8000 to 9000 tons distributed by gravitation (probably not with sufficient care, or proper laying out of ground); and Mr. Philip Miles gave evidence before the same Commission that he had about doubled the value of fourteen acres of land by carefully utilising the sewage of thirty people upon it, and that he calculated that there was realised a clear profit of £1 a year for each person's sewage, instead of Mr. Lawes's 1s. or 2s. There is nothing impossible in so high a profit; it merely shows the great value of the water itself—a consideration which may come to be an important one in future valuations of sewage.

Conclusions, as to value

Too much applied in above experiments.

Very high profit by economical use.

The above experiments are, however, most valuable from many points of view; but they do not give any account of results with other crops than grass and oats, and so we must turn to the results obtained at Lodge farm, Barking, and at Breton's farm, near Romford, in Essex. At the latter place we find from the evidence given by Mr. Wm. Hope, V.C., before the Reading Local Board of Health, that he rented a farm of 121 acres at £300 per annum, and that he paid in addition £600 a year for the sewage of the town of Romford delivered on to the farm, being equal to two shillings per annum for the sewage per head of the population, and that, moreover, he "agrees to bear the Board harmless in respect of all actions for any damages or nuisance." On this farm he has grown successfully all the crops above mentioned as grown at the Lodge farm near Barking; and on the 6th of August 1870 we saw very fine crops of almost every kind growing there, and remarked that several of them bore excellent evidence to the fact stated, that roots bear transplantation remarkably well when supplied with sewage. A crop of maize was exceedingly luxuriant, and gave every promise of ripening, and the only fault that could be found with a plot of oats was that they were too thick, the ears being especially heavy and of very remarkable length, in some cases as much as 27 inches. It may be stated as a proof that strawberries (a very valuable crop) thrive well, when supplied with sewage, that those the Lodge farm produced (in 1869) were the finest in Covent Garden Market, and fetched the highest price. Beet-root promises to be a crop of the greatest importance in sewage farms, and the manufacture of sugar from it would certainly realise a very large profit. Pro-

Breton's farm.

All kinds of crops.

Straw-berries.

Beet-root.

fessor Voelcker finds that the best beetroots grown in Holland, Suffolk, and Scotland give from nine to ten per cent of sugar at the outside, while the roots grown at the Lodge farm, with London sewage, give 13·19 per cent of it. There seems no reason why hops should not be manured with sewage, and indeed they would appear to be a crop especially suited for it, as they require to be manured while growing. From a paper read by Mr. Hope at the Institution of Surveyors, on 22d November 1869, we find that he considers Italian rye-grass to be the staple sewage crop, and that it will produce, under proper cultivation, ten crops, averaging nine or ten tons each per acre, in one season, by the application of a sufficient quantity of sewage—the grass being sown in the month of August; and that from the farmer's point of view the dilution of the sewage of a town should not be less, if possible, than from 25 to 30 gallons of liquid per head of the population daily. The sewage of thirty-five to forty persons per acre is a sufficient average for a term of years; but the difficulty in acquiring land often necessitates the application of a larger amount of sewage per acre, and the application of the sewage of 100 persons per acre may be taken as the ordinary standard.

Italian rye-grass.

Dilution of sewage.

The introduction of what is known as *Ensilage* into this country will probably find a very useful application on sewage farms, where large quantities of meadow grass and Italian rye-grass are grown. The difficulties in making hay are much increased on sewage farms as compared with ordinary farms from the large size of the crops and the great rapidity of their growth; and, especially in wet years, there may be no market for the Italian rye-grass when cut. If

Ensilage.

these crops be stored and compressed in what are known as "Silos," which are pits in the ground, or special receptacles of brick and cement rendered impermeable to air, they undergo a certain amount of fermentation which is subsequently checked by the absence of air and oxygen, and can then be kept for any length of time. It is found that ensilage is readily eaten by all kinds of cattle, and in the case of cows produces an increased flow of milk as compared with that produced by the ordinary diet of hay and roots in winter. It is by some considered best for the crops when cut to be left on the land for a day to dry, and then to be packed into the silo, at the bottom of which a means of exit for any water that may accumulate should be left. The fermentation which goes on to a limited extent causes a partial conversion of starch and sugar into lactic acid, but this loss is counterbalanced by the greater nutritive qualities of a fodder which is not dry, but still retains a large proportion of its water. Compression of the crops in the silo, to force out as much air as possible, and the impermeability of the walls of the silo to air, are necessary to ensure the production of good ensilage.

Method of production.

Fermentation in "Silos."

Professor Henry Robinson says in a paper on "Some Recent Phases of the Sewage Question,"

> If the green crop, after being placed in the silo, be left freely exposed to the air for a few days, it heats, and if the temperature be allowed to rise to from 125° to 150° Fahr., the bacteria are killed, and the subsequent fermentation which would have been produced by that cause is arrested. The resulting material is called "sweet" silage, which remains aromatic, after having gone through what is termed a "haying fermentation." If, on the other hand, as soon as the green crop is put in the chamber, it is subjected to pressure, by which the air is excluded as far as possible, and if the temperature does not rise above 100° Fahr. at the outside, the bacteria live and develop, and the fermentation is greater than before, leading to the formation of lactic or acetic acids, with a loss of some

"Sweet" silage.

of the saccharine matters, which become broken up and form new combinations which partly pass away as gases. The silage thus produced is called "sour," to distinguish it from that termed "sweet," although the difference does not affect the avidity with which cattle eat it, nor its nourishing results. The fermenting action which takes place in the silo is partial digestion, such as would have taken place in the animal's stomach. It causes a softening of woody fibre and a preservation of the flesh and fat producing ingredients of the green crop. The loss of weight produced by fermentation falls upon those parts of the fodder which have the least feeding effect, such loss comparing favourably with preservation of grass, etc., by exposure to the sun.

"Sour" silage.

The Committee of the British Association on the Treatment and Utilisation of Sewage made an estimate of the amount of nitrogen recovered in the crops from the sewage applied to Breton's farm, near Romford. These determinations were carried on from March 1871 to March 1872; the general results arrived at being that "of every 100 parts of nitrogen distributed over the farm during the twelve months, 10·67 parts, or about one-tenth, were found in the effluent water; 41·76, or approximately four-tenths, were recovered in the crops, making together about half; and 47·57 parts, or in round numbers the other half, were unaccounted for. Of this half a portion must have remained in the soil" (*Report*, 1872, p. 153). This was subsequently ascertained to be the fact, by comparing the analysis of the average composition of the soil of the farm made previously to the application of sewage with a similar analysis made in 1873 (*Report*, 1873, p. 417). The phosphoric acid in the soil was found to be increased from 0·01 to 0·058 per cent, the loss on ignition of the soil was much greater (leaving water out of the question), the amount of ammonia had increased from an inappreciable quantity to 0·016 per cent, and the amount of nitrates had also increased. The amount of total

Amount of nitrogen recovered in crops.

Enrichment of the soil of the farm.

nitrogen in the soil which had been sewaged was found by the soda-lime process to be 0·121 per cent. The Committee remark :—

"There is therefore no doubt that the quality of the soil has been considerably improved by the sewaging, and that a good deal, both of the nitrogen and phosphoric acid, is retained in it."

Nitrogen and phosphoric acid retained in the soil.

The samples of sewaged soil were very carefully taken, in the presence of members of the Committee, at the same part of the farm as the samples had been taken before the application of sewage. These samples were mixed, and an average sample submitted to analysis.

Proportions as exact as possible.

The Committee call attention prominently to the fact that the proportions, representing the manner in which the nitrogen of the sewage was ultimately disposed of in the case of Breton's farm during the twelve months, are " for the sewage and effluent water, as absolute and exact as accurate gauging and careful analysis can make them, and are, for the crops, calculated by means of the most reliable published data; they are, moreover, the final results obtained from a much greater number of continuously applied observations over a greater area, and with a much greater variety of crops, than have ever hitherto been scientifically made."

Two main results of the observations.

The Committee state that the two main results of practical importance which, from the evidence of the observations, may be accepted as generally attainable are :—" First, that less than 11 per cent of the total nitrogen applied to the land escaped in the effluent water, and of that only a fractional percentage in an organic form ; and secondly, that upwards of 40 per cent was actually recovered in the crops grown upon the land—a proportion which must be considered highly satisfactory (especially when the extreme porosity of the soil and limited area of the land are taken into account), as in the experiments of Messrs. Lawes and Gilbert only from 40 to 60 per cent of the nitrogen applied in solid manures was recovered in the crops within the season of application."

Tabular statement for five years.

The Committee subsequently extended their investigations on these points over a period of five years, the results being given in the following table:—

Year.	Sewage.	Nitrogen.			
		In Sewage.	In Crop.	Percentage recovered in Crops.	Recovered per acre of Farm.
	Tons.	Lbs.	Lbs.		Lbs.
1871-72	380,227	47,095	19,667	41·76	181
1872-73	523,810	60,438	15,704	26·00	145
1873-74	...	61,924[1]	22,766	36·74	210
1874-75	509,139	63,410	20,166	31·80	186
1875-76	546,982	67,765	20,558	30·34	189
		300,632	98,861	32·88	182

Average percentage of nitrogen recovered in crops during five years

In the above table is shown the amount of nitrogen applied to the farm in the sewage, and that recovered in the crops for each of the five years; and it appears that the amount of nitrogen recovered in the crops during the whole period is equal to 32·88 per cent of the amount applied in the sewage, and that the amount recovered per acre of the farm under crop averaged 182 lbs. It will be observed that the small amount of nitrogen recovered per acre during the year 1872-73 was compensated for by the unusually large amount recovered in 1873-74, which latter was due to the fact that certain crops taken off the ground in 1873-74 had derived the greater part of their nitrogen from

[1] As the sewage was not gauged in the year 1873-74, the amount of nitrogen applied is taken as the mean of that applied in the years 1872-73 and 1874-75.

the sewage of the previous year. The Committee observe that "the value of these results is much enlarged by the fact that they have been obtained by a series of observations and experiments extending over a period of five years, so that the effect of the inevitable annual variations, of which a notable example is furnished by the first three years, is got rid of." (*Report*, 1876, p. 230.)

THE SEWAGE FARM.

In order to obtain ground for the utilisation of the liquid sewage of a town where no private individual or company can be found to undertake to do so, paying the town for the privilege, it has been recommended by the Rivers Pollution Commissioners (1868) that,

Power to take land.

Subject to proper regulations to prevent abuse, additional powers be given to corporations, local boards, manufacturers, and others, to take land compulsorily, under "Provisional Order," for the purpose of cleansing sewage or other foul liquids, either by irrigation, filtration, or otherwise. (*First Report*, vol. i. p. 136.)

Well then, suppose the sewage to be carried out of a town in a covered sewer to the ground which has to be irrigated. This sewer would, of course, have to pass on its way, in many cases, through private property, and to this end the Commissioners recommend that the authorities above mentioned should have power

Compensation for damage to private property.

To obtain, if required, easements for the construction of culverts and outfalls for drainage through private property, making compensation only for damage actually done; reserving, however, to the owner the right at any time afterwards, if he could show further damage, to have further compensation.

In cases where the proprietors of land through which the culvert passes are desirous of obtaining sewage as manure for their own land, they could be allowed to take it at suitable places upon a payment for it according to the quantity required. It has been proposed that no difference should be made in the price of sewage at different distances from a town, but that it should be uniform, "upon the principle of the penny postage." Where the ground to be supplied is on a lower level than the town, the sewage would simply be allowed to run continuously without the interposition of any tank, unless it were considered advisable to have one for keeping the night sewage until the next morning, or unless it were proposed to strain or filter the sewage in some way before sending it on to the land, in order to separate the suspended solid matters. And here we must remark on the immense advantage that it would be to supplement the irrigation in every case, as is done at the North Surrey District School and some other places, by some method of simple filtration. In this way the most offensive and least valuable part of the sewage is separated from it before it is allowed to spread itself over the ground. The sewage is not by it appreciably diminished in strength, while the black mass remaining on the filter-beds could be mixed with town sweepings, or, in stone countries, where ashes are not required for brick-making, with these latter; and in this way a solid manure would be prepared very similar to the contents of ash-pits and middens, and which might, in some cases at any rate, be made to defray part of the expense of scavenging the town. We find, from the Report issued by the British Association Committee of 1869-70, that at one or two towns, and especially at Dundee, the contents of ash-pits and middens were made to pay for the cost of scavenging; while at the town mentioned, a profit of about $1\frac{1}{3}$d.

Invariable price.

Filtration advisable,

to separate the offensive suspended matters,

and utilise the ashes and street sweepings.

per head of the population was realised. The contents of the Lancashire ash-pits are so valuable in Lincolnshire, that they sell for prices which pay for the cost of their transport thither, but which do not, as we have seen, nearly pay for the cost of scavenging the towns. From these cases we may conclude that the manure prepared by filtration in the above-mentioned way, though possibly it might not be quite so valuable, would still help considerably to pay the expense of collecting ashes and street sweepings. But this way of preparing it would have the inestimable advantage of not being carried on all over the town from day to day, a practice which we have seen to be an especially unhealthy one. It would also, as a secondary advantage, afford the possibility of keeping all the ashes separate from the manure in countries where either the ashes are valuable of themselves, or, on the other hand, render the manure by their admixture with it, as is often the case, totally unfit for the soil. At the school above mentioned, it was found that four tons of clay ashes, with a quarter of a ton of peat charcoal, produced, by filtration of sewage through it, eight tons of manure at the end of a month. The effect of this manure on the crops, at the rate of 2 tons per acre, was equal to that of 20 tons of ordinary farmyard manure. The comparison was made by treating two plots with the quantities just mentioned for three seasons in succession: the result was that the crops were "as nearly similar as could be." This manure was found to be worth 10s. a ton, and the two tons per acre about equivalent to 4 cwt. of guano; but with crops subsequent to the first crop, the result was far superior with the sewage or farmyard manure than with the guano. As to the expense of production, it

Result would help to pay for scavenging the town.

Can preserve the ashes separate, where advisable.

Experience at North Surrey District Schools.

Value of the solid manure.

was found that the peat charcoal cost £3 : 3s. a ton (fine ashes, however, would in many towns be a worthless product, and so their expense would be that of carting). The clay cost 3s. a ton to burn it when on the spot, so that the filter, consisting of 4 tons of burnt clay and $\frac{1}{4}$ ton of charcoal, cost £1 : 8 : 9, and produced 8 tons of manure, worth £4. This manure being used for swedes and mangold wurzel, gave a result of 25 tons an acre: an unknown quantity of potatoes were also supplied with it. Wheat was sown after these roots, and produced 5 quarters to the acre, "except where guano was used, when the crop was considerably lighter, both in straw and corn." It must be noted that the soil of this farm is mostly a stiff clay. (*First Report on Sewage of Towns*, 1862: *Dr. Brady's Committee.*) Costs. Results on crops.

Whenever sewage has to be pumped, some sort of straining, through gratings or otherwise, *must* inevitably be resorted to in order to separate off the larger solid bodies that are brought down with it, and that are of the most varied nature. Separation of larger suspended substances.

In the cases, too, where simple filtration has been applied as the sole means of purifying the sewage, the manure has generally sold easily, and the filtrate, which was allowed to run away, has sometimes rendered the brook into which it has run valuable as an irrigating liquid for farms lower down.

The necessity of separating the grosser suspended matters from the sewage before allowing it to run on to the land is becoming more acknowledged every day, and may be accomplished in various ways. Simple depositing tanks are used in several places, and they seem to answer the purpose very well, the chief objection to them being the offence caused in removing Depositing tanks.

the accumulated deposit; this might, however, be obviated by the use of some cheap deodoriser, as we have before suggested. Filtration through beds of gravel has been tried, but presents few advantages; coarse ashes and charcoal, as in Weare's process, certainly form a much better filter bed, and have the advantage of being deodorisers, and of forming a more or less valuable solid manure.

Receiving tank.

But where the land to be irrigated is above the town, so that pumping must be had recourse to, as at Warwick, Banbury, Romford, etc., the sewage must be received into a tank or well, which should be covered, and provided with a high ventilating chimney. It is essentially necessary that it should so enter such tank that there is no chance of sewage being backed up in the sewer: and here we see the advantage of keeping the storm-waters out of the sewers; until this is done, it must happen, *in cases where the sewage has to be pumped,* that the well will get filled faster than the pumps can empty it, that the sewage will be backed up in the sewers with the ill effects already described, and that it will overflow from the tank; indeed, it would be necessary to provide a storm overflow for it: and although it may be contended that the sewage is so excessively dilute in such case that no harm would arise from its being allowed to enter the river, yet the answer must be that the manure would be lost, that the same amount of sewage would still enter the river although with a larger body of water, and that in towns where accumulation takes place in the sewers on account of their faulty construction or of want of regular flushing, the sewage so escaping is actually very much stronger than it is in ordinary times. The pumps must, of course, be double, so that one may be

Disadvantages of storm water.

used when the other is out of order, or even that the two may be used at once if necessary.

One horse-power will lift 3300 gallons of water one foot high in a minute, so that about 300 horse-power *nett*, working constantly, is required to raise ten million gallons 100 feet in twenty-four hours. Strong iron pipes are the only ones that are suitable on a large scale for pumping through. At Bedford, where the water supply does not much exceed 150,000 gallons daily, but where, from subsoil water, the amount of sewage to be pumped is as much as five or six hundred thousand gallons daily, two 12-horse-power engines are employed, each of which can lift 2000 gallons a minute to a height of 20 feet—obviously more than enough for the amount above given, and this is to allow for storm-water. The sewage is then pumped up to the highest point of the land to be irrigated, and here, as may be seen at Warwick, there is no necessity for a storage reservoir.

Power of pumps.

Example of power required.

Mr. Bailey Denton in his work on *Intermittent Downward Filtration*, 1885 (p. 48), recommends that storm overflows should be connected with osier beds.

> "The beds are formed in horizontal areas, which serve to *check* the rapidity of flow of suddenly discharged rainfall. This check causes the deposit of the floating solid matters in the furrows, while the flood-water rises and overflows the ridges and the osiers growing on them. These beds are not under-drained in any way ; their simple purpose being to clarify those excess waters which without the check afforded by them would be impetuously discharged, together with everything floating in them, into the natural streams of the water-shed."

Storm overflows connected with osier beds.

We have thus seen the sewage, filtered or not, delivered on to the farm in one of two ways ; it now remains to consider the most suitable manner of spreading it over the ground. The most obvious way is that of the "Marcite" meadows at Milan, namely, to let it run everywhere, in fact to produce "water meadows," separated from the land around by a bank. The disadvantages of this plan agriculturally are, that it waterlogs the soil, and that it is not suitable to all crops, injuring the upper parts of the plants; neither does it allow of *intermittent* downward filtration, which admits air, so essential to the growth of plants and to the purification of the sewage itself, especially when the land is fallow; so that the effluent water would not be purified at all times, as we have seen that it is not by *continuous* downward filtration.

Submersion not advantageous.

Hose and jet: advantages.

A plan, which once found a great many supporters, is that of *underground pipes and hose-and-jet* distribution. The advantages claimed for this plan are that by it every plant and every square inch of ground can be thoroughly supplied with the manure, and that it is the only method that is suitable for a variety of crops. That this is certainly not the case has been amply proved by experience. The objections, on the other hand, to this plan are, its great expense both as regards plant and labour; the fact that it applies the sewage to the tops of the plants rather than to the roots; that a stronger flow is required in order to overcome the friction in the pipes; and that it is well calculated to cause a nuisance to the neighbourhood. It is a plan that has been very successful on a small scale, but that could never be used on a large one; and Messrs. Lawes and Way concluded from their experiments (*Sewage of Towns, Third Report*, 1865) that sewage was not applicable to arable land because of the great expense that would attend its distribution by means of pipes and hose and jet. For this reason it had failed on the Duke of Northumberland's land near

Disadvantages.

Failure of hose and jet.

Alnwick, where the tenants gave it up rather than pay the cost of its application. This is entirely condemnatory of the hose-and-jet system, but it hardly warrants the assertion that sewage is inapplicable to arable land. (See paper by Messrs. Lawes and Gilbert in the *Journal of the Chemical Society*, April 1866.)

Subsoil irrigation.

It has also been proposed to carry the sewage to the plants by *subsoil* irrigation; that is to say, by porous pipes laid deep enough in the ground to be out of the way of the plough: and indeed it is suggested that sometimes the ordinary drainage pipes may be used for this purpose by stopping up their outlets during the time that the irrigation is going on: but this would obviously merely result in the majority of cases in the turning of the sewage continuously into the underground drains and so into the watercourses in which those drains discharge. The manurial value of the sewage would be lost to the plants, and the streams would be polluted. The plan, however, of subsoil irrigation has recently received a great impetus by the invention of self-acting flushing tanks, by means of which the sewage can be disposed of underground in the same manner as has been described for the waste water of sinks in chapter iv. p. 127. It is merely necessary that the sewage should pass through a straining chamber, before entering the flush tank, to separate the larger solid matters. Subsoil irrigation is especially advantageous for the disposal of the sewage of country houses, where for various reasons it may not be advisable to have recourse to surface irrigation.

Subsoil irrigation in America.

Some important modifications in the disposal of sewage by sub-surface irrigation have been introduced in America. Mr. Edward S. Philbrick, C.E., an American engineer, in a pamphlet on this subject (reprinted from the *Sanitary Engineer*), points out what he considers the limits of its application: "wherever a quarter of an acre of grass land is available for a single family of eight or ten persons, or an acre for an aggregate population of eighty persons so situated that the surface of the sod is five feet or more below the level of the house drain—where it leaves the house or houses—this system will dispose of all their sewage in a satisfactory manner, summer and winter, with very little attention—for a term of years—generally five to ten years at least before the distributing drains need cleansing, and often for a much longer period." In order to obtain the solid matter of the sewage in a finely divided state, and so prevent the blocking up of the tile drains laid in the soil, Mr. Philbrick says "it has been found necessary to provide a tank or tight cesspool in which the solid particles of the sewage may become macerated and finely divided by fermentation before entering the distributing pipes." This cesspool or settling-tank, which is ventilated by a special pipe, discharges into a flush-tank, by an elbowed iron pipe opening about one foot below the surface of the sewage, so that the overflow of the settling tank may not be from the surface or scum, nor from the sediment at the bottom. The top of the vertical part of the pipe is open so as to allow air to pass freely at all times from one tank to the other. The flush-tank is similar in principle to that of Mr. Rogers Field, but the siphon is placed on the outer wall of the tank in a manhole chamber, so that it can be easily reached for examination. The V-shaped notch in the weir at the lower end of the discharging siphon in Mr. Field's tank has been found by Mr. Philbrick, in cases where the volume of sewage discharged is small—as from

Limits of application.

Settling tank necessary.

The flush-tank.

one house—to become "choked with particles of solid matter brought along and deposited by the sewage" so that its function of draining away the water behind the weir after the tank is discharged, and thus unsealing the lower end of the siphon, is not performed. Consequently the cup remains full, the large siphon also remains full, or nearly so, and prevents the tank being filled again, by drawing off its water by driblets as fast as it comes from the house. The notch then requires to be cleaned out as often as it becomes choked. To remedy this evil, Mr. Philbrick has introduced a modification: "instead of cutting a V-shaped notch in the edge of the cup at the lower end of the siphon, or using a small siphon to discharge the cup, it is proposed to abandon the cup, making instead a channel in the direction intended for the outlet, and contract the sides of this channel at a point about a foot from the end of the siphon, so that they shall obstruct the flow and raise the level of the water to such a height as to seal the end of the siphon whenever a slight flow begins. Since this narrowing of the sides is made very gradual by smooth flowing curved lines, and the sides are formed of cement, trowelled smoothly and carefully, and expanding again below in the same manner, the channel is found to keep itself clear of rubbish, and needs no attention to keep it free."

Notch in weir liable to be choked.

Contracting the sides of the channel.

Allows no deposit.

The siphon can be constructed of lead pipe. A 2-inch pipe is large enough for a single house or family. Both settling and flush-tanks may be constructed of brickwork, lined inside with hydraulic cement. To make the siphon work well, the portion of the channel under the outlet of the siphon should be, for a 2-inch pipe, at least $2\frac{1}{2}$ inches deep below the end of the pipe, and the bottom of the draining channel, where narrowed

Dimensions of the channel.

up, should be from $\frac{1}{4}$ to $\frac{1}{2}$ an inch below the end of the pipe. This narrow part of the channel should not be wider than $\frac{3}{8}$ inch at the bottom. The outlet should be a 4 or 5-inch stoneware pipe. The distributing pipes should be of porous earthenware, cylindrical, 1 foot in length, and 2 inches bore, laid so as to conform to the contour of the surface, about 5 or 6 feet apart, with a perfectly uniform slope of about 6 or 8 inches in 100 feet. They should not be laid deeper than 8 inches below the surface of the ground, so that air and the roots of the grass may get ready access to the sewage. The joints of the distributing pipes should be laid at least $\frac{1}{4}$ inch open and supported on terra-cotta troughs. The length of the distributing drains needed will vary with the porosity of the soil and the size of the flush-tank. The lower end of the main outlet pipe should turn up into the air, to allow air to escape when the water and sewage rush in. The plot of ground must be under-drained, naturally or artificially.

The distributing pipes.

Remarks.

It is necessary, however, to observe that the tank used in connection with sub-irrigation works in this country is generally fitted with Mr. Field's annular siphon, with which a notch in the weir is not required, so that the difficulty experienced by Mr. Philbrick is not found to exist. Neither is it found to be necessary to collect the sewage in a cesspool before it passes into a siphon tank, but merely to pass it through a strainer to separate adventitious solid matters which might block up the siphon, or the subsoil drains. If this were not the case, one of the strongest arguments for the adoption of this system, viz. that by it cesspools are abolished, would be destroyed.

For the disposal of the sewage of towns, however, surface irrigation is for many reasons the most advisable plan. The utilisation is more complete, the purification is more certainly ensured, and surface carriers are more easily cleansed than underground drains. It therefore becomes important to know whether the sewage is likely to lose any proportion of its most valuable constituent, ammonia, by passage in open channels (particularly if open conduits be used for carrying it from the town to the farm). The Rivers Pollution Commissioners (1868) made some experiments on this point (*First Report*, vol. i. p. 93). They found that on exposing a solution of carbonate of ammonia containing 9·75 parts in 100,000, in a layer of 12½ inches deep, continually to a strong draught of air, the loss from it during the first three days was perfectly inappreciable, and in sixteen days only amounted to 1·5 part per 100,000; while even the loss of another solution containing 9·25 parts, and in a layer of only 2 inches deep, was after twenty-four hours absolutely inappreciable, and after three days the solution still contained the same proportionate amount of ammonia; that is to say, it lost ammonia precisely in proportion to the evaporation that took place; or, in other words, the difference between the volatility of the ammonia and that of the water in such solution and after such a time is, under the most favourable conditions, inappreciable. "Even after the lapse of three days the proportional loss amounted to little over 13 per cent. At the rate of only one mile per hour, sewage would during this time have travelled 72 miles." The layer 2 inches deep lost over 13 per cent in three days, while that 12½ inches deep lost only 2½ per cent in the same time; that is to say, that, seeing the sewage in a conduit would be generally of some such depth as this or deeper, "the

Surface irrigation by open channels.

Experiments with a solution of carbonate of ammonia.

Inappreciable loss of ammonia in twenty-four hours.

Open culverts.

appreciable loss of fertilising effect, from the evaporation of carbonate of ammonia during its flow along a conduit of any length likely to be constructed, need not be feared." Dr. Hofmann, too, stated before Dr. Brady's Committee, that after a flow of 10 miles in an open culvert (with a medium temperature) it would be in very much the same condition as before. The objection raised to open conduits therefore vanishes, though in many cases it would no doubt be advisable to cover them over (as the Romans did their aqueducts) in order to prevent improper substances being put into them. For carriers raised above the ground, wherever it is desirable to use these, sheet-iron has been found to be a very suitable material. It should be well painted inside and out; no accumulation takes place in it, and a suitable incline for these carriers is that of 5 inches in 100 yards. The beds should run at right angles to these carriers, and the carriers be so placed that the beds slope from them. At intervals along the carriers, taps of some simple construction should be placed, so that the sewage may be turned on when required for any particular plot. Where iron carriers are not necessary, carriers made of concrete, or stoneware channel-pipes, as at Tunbridge Wells, are found to answer the purpose satisfactorily. If the sewage were well filtered, the use of concrete or stoneware carriers would be the less necessary, although they would always be preferable to open ditches. With unfiltered sewage they are absolutely necessary, as the deposit from it cakes on the sides of the ditches and produces an offensive smell. This we have noticed at Croydon, in the Beddington meadows. When the sewage is delivered by pumping to the highest point of the farm, and the ground is very sloping, it may

Iron carriers.

Concrete and stone ware carriers.

Deposit in bad carriers.

be preferable to resort, as at Warwick, to the "*catch-water*" system, which consists in running carriers down the slope of the hill and along the fields, so that they are more or less parallel to each other, and the overflow from the higher ones falls into those below. With a general slight fall of the land, the "*pane and gutter*" system, in use at Croydon, may be employed. By it the sewage is taken by the minor carriers along the fields *across* the direction of the greatest fall, and allowed simply to spread over the surface of the beds from above downwards; but as a general rule the best plan is doubtless the "*ridge and furrow*" system, in which each plot consists of a ridge, that is to say, falls away on each side from the centre. At Bedford, the beds "are about 70 feet wide on the side, with a fall of 8 or 10 inches from the central carrier to the midway furrow;" while at Breton's farm a breadth of 30 ft. (15 ft. "on the side") has been found most suitable.

"Catch-water" system on hilly ground.

"Pane and gutter" on gentle slopes.

"Ridge and furrow," best plan, as a rule.

The simplest contrivances only are necessary to stop the sewage from certain beds and turn it on to others. Along the summit of each ridge is merely a small furrow along which the sewage is allowed to run; the workman should walk down the bed with an iron plate in his hand, with which he stops the sewage at intervals, so as to force it to run over the surface of the bed on each side of the small furrow. It is not very material whether this be done from above downwards or from below upwards; in fact, it may be done alternately by going down one bed and up the next, the sewage being turned on and off, as required, by a boy.

Distribution of sewage to the beds.

At Carlisle the sewage is distributed over the land by means of light portable iron troughs, which can

Portable carriers.

be shifted about by the workman so as to deliver it at any required point.

Drains.

One great condition for the successful purification of the sewage is that the land should be well drained; and clay lands must be broken up and treated with town ashes and lime, so as to facilitate the drainage, otherwise the sewage will run over the surface and run the risk of not being purified. Six feet deep is a good average depth for them on tolerably porous soil.

Advantage of "separate" system.

As to the dilution of the sewage, it is certain that it would be more valuable as a general rule to the farmer if the rain and subsoil water could be kept out of it, as by a separate system of drains and sewers, although it is also certain that in many cases this proceeding would render the sewage too strong; so that it would be advisable that it should be possible to connect the drains with the sewers, not merely, as above stated, for flushing purposes, but, when required, to dilute the sewage. That this is true is seen from the fact that at Breton's farm it was necessary, during the very dry season of 1870, to turn all the effluent water sometimes, and invariably the greater part of it, back into the tank, to be re-pumped over the ground with the sewage. To show the advantage of liquid manures over solid, we may quote Alderman Mechi's evidence before Lord Robert Montagu's Committee. He says that farmers would find it worth their while to take regular supplies of sewage, "even if they paid 2½d. or 3d. per ton, because, if it suits me at certain seasons during the summer, when there is growth, to pay 2d. a ton for water to wash in the guano, which does answer, it would answer to pay (although we should like to have it cheaper) from 2d. to 3d. per ton for sewage"

But sewage may require dilution.

Necessity of water.

(*Committee on Sewage*, 1864, p. 141), though it would probably not answer to pay that price for it except when water is most wanted.

With regard to the question of its use in winter, when it must also be pumped on to the land, we may point out that most lands have the power of purifying it, and of retaining its valuable constituents boxed up, for use at a future time; and that, moreover, it is certain that by sewaging through the winter a very much earlier crop is got in the spring. The evidence from Milan must also not be omitted, showing a great advantage to the crops from the *warmth of the water* passing away from the town. Value in winter.

The difficulty arising in very wet seasons would be to a great extent got over by keeping the rain and subsoil water out of the sewers; while in dry seasons the farmer is sure of his crops, as he is perfectly independent of drought. Wet seasons. Droughts.

It has been already mentioned (p. 331) that sewer-fungus was found growing abundantly on submerged objects, near the banks of the Leam: it is also commonly found on the carriers in sewage farms and in effluent waters. A knowledge of this "sewer-" or "sewage-fungus" is important, as it has been held to constitute, when found on the banks of rivers, evidence of the pollution of such rivers with sewage, or with a more or less unpurified sewage effluent. Sewage-fungus.

The following particulars are derived from an article on *Beggiatoa Alba*: *the so-called "Sewage Fungus,"* by Mr. Alfred W. Bennett, in the "Pharmaceutical Journal and Transactions," 3d May 1884. The organism occurs abundantly in the effluent water from sewage works, forming dense flocculent grayish-white masses attached to the bottom and sides of the channels, or to ordinary green algæ. Under the microscope it is seen to consist of an immense quantity of colourless threads, with but little or no chlorophyll, full of granular protoplasm, and containing a number of bright strongly refractive granular particles, of globular form, which have been determined by Professor Cohn of Breslau, and Professor Cramer of Zürich to consist of pure sulphur. Mr. Bennett found the filaments to be copiously branched, either dichotomously or laterally, and septated, either at the bases of the branches or elsewhere. Zopf describes the filaments as varying greatly in diameter, from 1 to 5 mm., and as being unbranched and unseptated. He also describes the fungus as occurring in the effluent water from manufactories, especially sugar factories and tanneries, and in thermal sulphur springs, as well as in drains. Mr. Bennett has himself seen what he has no doubt was the *Beggiatoa Alba* in large quantities on the waste ground about alkali works near Jarrow-on-Tyne. "It, therefore, has probably the power of extracting the sulphur not only from decomposing organic matter, but also from mineral sulphates dissolved in the water; though the absence of chlorophyll would indicate that it is dependent on decaying organic substances for its carbon." In the locality where he had the opportunity of examining the *Beggiatoa*, there is abundance of sulphates provided for its nutriment. The sewage of Hertford is carried into the river Lea after being treated by a modification of the process known as Anderson's, consisting essentially in precipitation by sulphate of alumina, lime, and protosulphate of iron; and it was from the open channel which conducts the water, after being so treated, into

Microscopic appearances.

Occurs in the effluent waters of factories as well as in sewage.

the Lea, that he obtained his specimens. "The growth of the so-called 'sewage-fungus' must undoubtedly be regarded as evidence of the presence in the water of an abnormal amount of sulphates, derived either directly from the sewage or from the substances used in precipitating it, or in other ways in manufactories. But there seems no reason to believe that it will itself have any injurious effect on the water."

COMMERCIAL ASPECTS OF SEWAGE FARMING.

The following table shows the financial results obtained from the disposal of sewage by irrigation at sixteen towns. At Blackburn, Cheltenham, Chorley, Doncaster, Leamington, Wolverhampton, and West Derby, the cost of cleansing and removing the contents of privies, middens, and ashpits, varies from 3¾d. in the pound on the rateable value in the case of Blackburn, to ½d. in the pound in the case of Cheltenham, in addition to the cost of disposing of the sewage proper. At Merthyr-Tydfil and Kendal the privies are cleansed at the expense of the occupiers of the houses to which they belong. In the remaining towns given in the table there are no privies or middens.

Cost of cleansing and removing contents of privies, etc.

It will be seen from the table that, judging by the results of one year, after repayment of capital for outlay on works connected with the sewage farms, in eleven towns out of the sixteen there will be a profit to the ratepayers from the sewage. Of the remaining five towns where there will be no profit, in one (Leamington), the cost of pumping the sewage 130 feet is very great; in another (Warwick), besides the expense of pumping the sewage 64 feet, there is no profit rent from the farm which is sub-let by the Corporation. In

Profit from sewage after repayment of capital.

Table of Incomes and Expenditures of Sewage Farms for the Year 1875.

	Population.	Rateable Value.	Daily flow of Sewage.	Volume of Sewage per head.	Sewage pumped	Acres of land irrigated.	Nature of soil of Farm.	No. of inhabitants to each acre.	Rent obtained for Farm.	or Yearly produce of Farm.	= Per ton of Sewage.	Cost of Disposal of Sewage. Rate per £1 of Rateable Value.	Per ton of Sewage.	Per head of Population.	Future Rate per £1 Rateable Value, after repayment of Capital for outlay on Works.
			Gallons.	Gallons.											
Banbury .	12,000	£34,104	320,000	27	21 ft.	138	Stiff loam on clay subsoil.	87	..	£1451	$\frac{11}{24}$d.	1d.	$\frac{1}{24}$d.	3d.	Profit of 1¼d.
Bedford . .	18,000	65,000	700,000	39	Yes.	155	Rich loam on gravelly subsoil.	116	..	3461	$\frac{15}{24}$d.	1d.	$\frac{5}{24}$d.	4¾d.	Profit of 1d.
Blackburn .	90,000	235,127	1,500,000	17	No.	90	Light loam on gravelly subsoil.	1000	..	5781	$\frac{23}{24}$d.	7¾d.	$\frac{15}{24}$d.	1s. 8¼d.	Loss of 1¼d.
Cheltenham	45,000	217,849	1,250,000	28	No.	131 (200 occasionally)	Stiff clay.	195	£1304 (£348 for sludge)	..	$\frac{15}{24}$d.	½d.	$\frac{1}{24}$d.	1¼d.	Profit of ⅔d.
Chorley . .	20,000	54,407	500,000	25	No.	133	Poor vegetable on stiff clay subsoil.	150	90	847	$\frac{15}{24}$d.	4¾d.	$\frac{11}{24}$d.	1s.	Profit of $\frac{1}{20}$d.
Doncaster .	20,000	68,721	600,000	30	52 ft.	264	Partly open, partly clay.	77	470	..	$\frac{7}{24}$d.	3⅓d.	$\frac{15}{24}$d.	1s. 0¼d.	Profit of ¾d.
Harrogate .	12,000	50,000	210,000	18	No.	60	Stiff clay.	200	52	570	$\frac{23}{24}$d.	5⅓d.	$\frac{23}{24}$d.	1s. 11¾d.	Profit of ½d.
Leamington	24,700	113,400	700,000	28	130 ft.	350	Fine loam on gravel subsoil.	70	450	..	$\frac{7}{24}$d.	5d.	$\frac{23}{24}$d.	1s. 11½d.	Loss of 1¼d.
Merthyr-Tydfil	55,000	135,000	1,200,000	22	No.	250	do.	220	..	1623	$\frac{13}{24}$d.	7½d.	$\frac{21}{24}$d.	1s. 6½d.	Loss of 1¾d.
Rugby . . .	8,400	45,000	400,000	48	No.	78	do.	107	429	..	$\frac{11}{24}$d.	1⅓d.	$\frac{5}{24}$d.	7½d.	Profit of ½d.
Tunbridge Wells	23,000	142,914	650,000	28	No.	218	100 stiff loam, 118 light open.	105	..	7671	1⅓d.	10d.	1¼d.	5s. 2¼d.	Loss of 1½d.
Warwick .	11,000	43,339	700,000	64	64 ft.	135	Stiff clay.	81	..	..	..	6½d.	⅜d.	2s. 1½d.	Loss of 3¼d.
Wolverhampton	71,000	210,000	2,500,000	35	No.	248	do.	284	..	5097	¼d.	2d.	⅛d.	5½d.	Profit of ¾d.
West Derby	31,400	163,000	750,000	24	No.	207	do.	151	..	3350	⅜d.	4⅓d.	⅛d.	1s. 9d.	Profit of 1½d.
Wrexham .	10,000	32,000	300,000	30	No.	84	Open soil on sandy subsoil.	119	350	..	⅞d.	Profit of ⅓d.	..	..	..
Kendal . .	13,700	44,600	750,000	55	No.	5 (11 occasionally)	Fine sandy loam on gravelly subsoil	2740	495	..	⅛d.	4d.	¼d.	1s. 1d.	Profit of 2d.

This Table is compiled from the Abstracts of the cost of dealing with Sewage by Irrigation, given in the Report of the Committee of the Local Government Board on Modes of treating Town Sewage (1876).

the case of the other three towns (Blackburn, Merthyr-Tydfil, and Tunbridge Wells), the cost of distributing the sewage and the working expenses of the farms are very large; but it is reasonable to suppose that with increased experience these expenses will be reduced, and the farms in time made to yield a profit.

Large costs.

From the Report of the Local Government Board Committee (pp. 59, 60), we find that at Blackburn, Harrogate, and Tunbridge Wells, very large sums have been paid in parliamentary and legal costs, and these items have been charged to the capital account; but, observe the Committee, "it may fairly be said that such items are not necessarily part of the expenses to be incurred in providing sewage farms." As to the price of land we are told that "land rented at 20s. or 30s. an acre, when required for a sewage farm, is sometimes valued at several hundreds of pounds per acre;" and in the case of Blackburn, "portions of the land obtained for sewage irrigation purposes have cost about one hundred and fifty years' purchase."

Parliamentary and legal costs.

Price of land.

At Cheltenham, dressings of sewage are sold to the adjoining farmers at a price per acre of 7s., or as may be agreed upon, and the Committee anticipate that "many towns, when they have established sewage farms, will find relief in this direction."

Sewage sold to adjoining farmers.

It having been already shown that the disposal of town sewage on land by irrigation is the system which should be adopted by town authorities wherever practicable, we may now indicate briefly the conditions upon which sewage farming may be undertaken, and the methods which should be adopted so as to yield the largest returns.

In the first place, it is generally agreed that it is better for the town authorities to let the sewage and

Sewage farm should be let.

farm to a capable individual on favourable terms, binding him, however, to purify the sewage effectually and to cause no nuisance, than to undertake the management of the farm themselves.

Situation of land.

The land for irrigation should, if possible, be so situated that the sewage may flow from the town to it by gravitation; for the cost of pumping sewage greatly reduces any profits that arise from the sale of sewage-grown produce. Arrangements should be made so that farmers adjoining the line of outfall sewers may be able at any time to obtain sewage for irrigating their fields at a price to be agreed upon.

Rent and extent of land.

The rent to be given for the land should not exceed £2 : 10s. an acre, as a general rule; and the extent of land acquired should not exceed that which will satisfy the demands of local markets for vegetables and grass produced from it. (Bailey Denton.) As an average an acre to every 100 persons of the population is sufficient.

Soil of the farm.

A portion of the farm should be laid out as a filter-bed.

The soil best adapted for irrigation is a friable loam, and the farm should have, if possible, a gentle slope to the south. A portion of the farm where the soil is most porous should be specially prepared and set apart as a land filter, and for this purpose should be closely drained 6 feet deep. The land may be laid out in ridges and furrows, and vegetables may be grown on the ridges. This filtering area should be subdivided into plots, and be of sufficient extent to purify the whole of the sewage by intermittent downward filtration, when, from any reason, it is inadvisable to apply the sewage to the general surface of the farm.

Under-drainage.

Where the soil is very light and porous only a few underdrains will be required for the rest of the farm, but where the soil is of medium consistence under-drainage should be thoroughly carried out.

Amount of capital required.

The amount of capital required to stock and work a sewage farm will be very greatly in excess of that required for an ordinary farm. The Local Government Board Committee were of opinion that five times the usual amount of money would be needed for a sewage farm upon which most of the produce is consumed.

Amount of labour.

In any case the amount of labour required on a sewage farm to keep the land clean and free from weeds and to deal with the enormous crops that are grown, must be greatly in excess of that required on ordinary arable land.

Italian rye-grass the most profitable crop.

As to the most profitable crops to be grown on the sewage farm the Local Government Board Committee were of opinion (*Report*, 1876, p. 29) that: "Italian rye-grass is probably in all respects the most advantageous crop to be grown under sewage, as it absorbs the largest volume of sewage, occupies the soil so as to choke down weeds, comes early into the market in spring, continues through the summer and autumn, bearing from five to as many as seven cuttings in the year, and producing from 30 to 50 tons of wholesome grass upon each acre. The area placed under this crop must, however, have reference to local means of consumption, as the young grass will not keep nor bear long carriage. It is most profitable for feeding milch cows.

A dairy should be associated with a sewage farm.

A dairy and a sewage farm should, therefore, wherever practicable, be associated. In a dry and warm summer good hay may be made, which will be sweet and wholesome." (For Ensilage, see p. 417.)

Other crops.

After two or three years the rye-grass should be ploughed up. Yearly rotation is best for nearly all other crops which are grown on sewaged land. Besides Italian rye-grass, cabbage and mangold wurzel were considered by the Committee "to be the only farm crops that persistently flourish upon any soils, heavy or light, under continual doses of town sewage," and they further state that "no growing crop, save natural grass, should be sewaged during the depth of winter; and for potatoes, turnips, most vegetables, and certainly for all pulse and cereals, the land ought rather to be enriched by frequent irrigation in the preceding season, than treated with sewage when these crops are growing; except in times of great drought, and even then care is requisite." This, of course, could always be managed if every sewage farm were provided with a land filter to dispose of the sewage when not required for the fertilisation of the land.

Growing crops should not be sewaged.

The Leamington sewage farm which gained the prize in the sewage farm competition of 1879 in the class for farms utilising the sewage of more than 20,000 people, is an example of the success with which, under favourable circumstances, sewage farming may be undertaken. From the report of the judges (*Journal of the Royal Agricultural Society*, 1880, pp. 39, 40, 41) we find that the average annual balance profit of the farm for the three years 1876, 1877, 1878, was £675. No doubt the farm enjoys some special advantages, all of which, say the judges, "have been made the most of."

A successful example of sewage farming.

The quality of the sewage is good, and in no other district did the judges find "such facilities for selling the produce of the farm. The prejudices which still exist in many parts of England against milk, rye-grass, and vegetables grown by sewage have here all been overcome, if they ever existed, and in all seasons

Prejudices against sewage-grown produce have been overcome.

there are customers for all that is grown." The profit of £675 would pay not quite 4½ per cent per annum interest upon the capital which has been invested. The farm pays £450 a year to the Leamington Corporation for the sewage.

From the same Report (*Journal of the Royal Agricultural Society*, vol. xvi. part i. p. 2), it appears from the examination of the statement of accounts furnished by the competing farms that "the profit or loss on a sewage farm is almost entirely dependent upon the amount of rent, rates, and taxes which are paid." The conclusions to be drawn from their investigations lead the judges to state that, Conclusions of the judges.

Practically, there appears to be no great value in sewage itself; but that given an ordinary farm and a sewage farm at the same rent, the sewage farm will hold its own even in a wet and backward year like the past, but in dry periods the sewage farm has a much greater advantage over an ordinary farm. As a mode of effectually disposing of sewage in an innocuous manner, and generally in an economical way, an examination of the several farms and of their accounts shows that the system pursued is most successful and satisfactory. The advantage and economy of sewage farming, as a mode of dealing with sewage, are shown very conclusively in the case of Birmingham, in which the farming operations show a profit of £1064 : 18 : 7 in the year 1878, while the chemical treatment of the sewage, two-thirds of which is passed into the streams of the district after such treatment, cost in the same year £11,987 : 15 : 3.

We conclude, then, from the facts brought forward in this chapter— Conclusions.

(*a*) That by careful and well-conducted sewage irrigation (especially if combined with a filtration area) the purification of the whole liquid refuse of a town is practically perfect, and has been ensured in cases where it was not at all the object of the agriculturist; and that it is the only process known by which that purification can be effected on a large or small scale. Purification of the liquid refuse practically perfect.

Increase of value of land;

(*b*) That perfectly worthless land, blowing sea-sand for instance, can be made in this way to support large and valuable crops.

of crops.

(*c*) That the quantity per acre of all crops obtained from even the best land is enormously increased.

Needlessness of artificial manures.

(*d*) That it reduces to a great extent, or renders entirely unnecessary, the usual amount of artificial manures of all kinds, by supplying a manure especially adapted, from its complex constitution, for the nourishment of crops, supplying it, moreover, in a state of solution, that is to say, in the most readily absorbable condition, and supplying at the same time that most necessary aid to vegetation, water, which often converts what would otherwise have been a heavy loss into a very handsome profit.

Farmer independent of drought.

(*e*) That by it the farmer is rendered entirely independent of drought, so that he can be practically certain of his crops, and, moreover, be able to transplant them as much as he pleases.

Pays, and will pay.

(*f*) That when circumstances are favourable it has been found to pay; and when its management is more thoroughly understood, it will doubtless, in many instances, be found to be a source of income to the towns. Where the circumstances are not so favourable, it will yet prove to be the most satisfactory way to get rid of the nuisance, although it may not entirely pay its expenses.

CHAPTER XII

INFLUENCE OF SEWAGE FARMING ON THE PUBLIC HEALTH

As far as nuisance is concerned, there is no doubt that if irrigation farms are badly managed they may be made a nuisance to the neighbourhood. Ordinary sewage is only in a very slight degree offensive when fresh, as every one knows who has examined it. Thus Dr. Hofmann says, in his evidence before the Select Committee on Sewage, 1862 (Dr. Brady's Committee) that sewage at the mouth of a sewer is "comparatively little offensive," and that irrigation is possible without annoyance, except in very hot seasons; adding, that sewage is only offensive when kept in tanks. What is really the most offensive part of sewage farms is the black slimy mud which collects along the sides of carriers when they are merely grips in the land, and when the sewage is not filtered before being sent on to the fields. We think that it is advisable that the sewage should be filtered or strained in the manner practised at several places. There is no reason to spread a layer of comparatively worthless and necessarily offensive filth over the surface of the soil.

Fresh sewage not offensive.

Offensive deposit in bad carriers.

Necessity of filtration to obviate this.

At Carlisle, indeed, the sewage is (1870) deodorised by admixture—as before stated—with carbolic acid. The deodorisation is complete, "no nuisance is

Deodorisation with carbolic acid.

made by them (the works) or by the refuse water discharged into the river" (*Ninth Report, Medical Officer of the Privy Council*); but it would appear, as may be expected, that this addition is, to say the least, no improvement to the sewage regarded as manure. The Earl of Essex says that the irrigation of fields creates no more nuisance than the application of any other manure. This is certainly the case, and indeed no irrigated fields that we have seen give offence to be compared for a moment with that produced by the application of stale farmyard manure. But this is not enough; the careful application of sewage which is fresh and not offensive in itself does not as a matter of fact produce any offence at all at the time, and need never do so if the simple plan above mentioned is resorted to, as it is at the North Surrey District School and other places.

Nuisance: that of ordinary manure;

or is less.

Need not be any.

Dr. Cresswell says of the farm at Norwood: "As for effluvia, I will not say that there does not exist any, but it is so seldom perceptible that a house built within 200 or 300 yards would command the same rent as if half a mile off."

The Earl of Essex says (Dr. Brady's Committee) that there is a smell during the momentary application of the sewage; "five minutes after there is not the slightest smell whatever, the bad smell is entirely absorbed by the land."

Smell during application.

It is agreed on all hands that the nuisance created depends on the quantity of sewage applied, and on the way in which it is applied; thus at Beddington there is "occasional nuisance owing to foul ditches, or perhaps to the ponding of foul water in hollows on the land."

Dr. Ligertwood, surgeon to the 8th Hussars, stationed at the Piershill Barracks, says: "These fields are certainly a source of nuisance to those living in barracks, from the offensive emanations given off from the open ditches conveying the sewage, and also from injudicious flushing of the fields; the stench in barracks is sometimes quite sickening. All this might, however, be remedied by the sewage being conveyed to the fields in covered ditches or pipes, and outlets placed on the pipes in the fields at proper intervals for irrigating." (*First Report R. P. C.*, 1868, vol. i. p. 90.)

Nuisance from bad management.

No such nuisance ought to exist, as it is simply the result of carelessness, and it is the duty of the Sanitary Authority to see that it is prevented.

On the other hand, Dr. Alfred Carpenter says:—

> At Norwood, moreover, a public footpath passes right through the irrigated fields, which is traversed by hundreds of persons for exercise and recreation, especially on Sundays. The persons so using the footpath have been frequently surprised when they have been told that their walks for pleasure have been taken through the sewage farm of the Croydon Local Board of Health. The path is much more frequented than other footpaths in the neighbourhood, which would not be the case if the fields were the nuisance they are supposed to be.—*Some Points in the Physiological and Medical Aspect of Sewage Irrigation*, p. 35.

No nuisance if well managed.

We can most fully bear witness to this fact; persons who have accompanied us to see sewage farms have been invariably surprised at the absence of nuisance.

The opponents of the irrigation system have often put very strongly forward the nuisance that is caused by badly-managed irrigation farms as an argument against the *system*, and have appealed to the opinions of medical men and others as to whether such a condition of things is *likely to be* healthful or otherwise; they have, however, rather neglected to bring forward the facts which have been ascertained on this head. This we now propose to do.

SANITARY EVIDENCE.

Submersion plan: paludal diseases.

Sewage farms are not meant to be marshes. Where they are so, that is, where the system of submersion is carried on, as is the case at Milan, there can be no doubt that the diseases of marshy districts are generated in their neighbourhood. The Sewage Commissioners, in their Preliminary Report (1858, p. 42), state that near to Milan they found that—

> The population who lived in the midst of and close upon irrigated lands are subject to the same diseases as are common wherever extensive tracts of vegetation are alternately covered with water, and then exposed when comparatively dry to the action of the atmosphere under a hot sun.

Limitation of fever area.

But even here, under the sun of Italy, and with the fields turned confessedly into water meadows, the intermittent and remittent fevers do not extend beyond a quarter of a mile from the marsh; and it was found that "although those irrigations have been brought close to the walls of Milan, and in some instances carried even within the walls, ague is never endemic in the city, nor is any other form of marsh-disease known spontaneously to arise within it." The soil is, however, very porous, so that the water does not stagnate on it for a considerable length of time. The Commission, however, got at Milan "striking evidence of the conditions under which irrigation with water containing no sewage may be so conducted as to produce with certainty a marked injurious effect upon the health of the neighbouring population;" and also of "the conditions under which entire immunity from disease may be secured." They could obtain

Irrigation with water containing *no* sewage: danger.

Conditions of immunity.

"no evidence whatever of the slightest increased injurious tendency of the irrigations conducted with the waters of the Vettabbia, beyond those of other districts around where plain water is employed." With regard to *typhus* and *typhoid* fevers, it is stated that they are not more prevalent near to the irrigated meadows than anywhere else. As to *cholera*, it appears that in a farm "irrigated entirely with the waters of the Vettabbia, though there have been three visitations of epidemic cholera in Milan and the neighbourhood, no case of the disease occurred during either of these attacks."

No influence on typhus and typhoid fevers.

Especial freedom of irrigated land from cholera.

This evidence, which is sometimes brought forward against the establishment of irrigation farms in England, simply shows what was perfectly well known before, that in the neighbourhood of *stagnant marshes* intermittent fevers are almost invariably endemic. The irrigation at Milan is copied from the fields where rice is cultivated around the same city, and where the water is allowed to remain and to stagnate; this is necessary for the cultivation of rice. The ordinary irrigated fields of Milan are not only irrigated by submersion, but they are not drained, and the porosity of the soil is alone relied upon for carrying off the water. In fact, the Commissioners came ultimately to the conclusion that no increased amount of disease could be traced to the admixture of sewage with the water of a "marcite." No one proposes to introduce water meadows or rice plantations into England, and the only thing that might be reasonably feared from sewage irrigation is increase of typhoid fever or of cholera, the evidence from Milan on this head being particularly valuable and especially favourable.

Intermittent fevers caused by stagnant marshes.

Faults of system at Milan,

nothing to do with sewage.

To come, then, to the evidence obtained from sewage farms properly so called: and first as to Edinburgh, where sewage has been so long employed in this manner, and even in a somewhat careless way. Professor Christison's evidence is very conclusive upon this point. He says of the irrigation fields:—

Irrigation farms.

No disease caused.

I am satisfied neither typhus, nor enteric fever, nor dysentery, nor cholera, is to be encountered in or around them, whether in epidemic or non-epidemic seasons, more than in any other agricultural district of the neighbourhood. (*First Report R. P. C.*, vol. i. p. 90.)

Dr. Littlejohn, too (the Medical Officer of Health of Edinburgh), although looking "with prejudice and displeasure on the existence of sewage meadows in its suburbs, had not been able to connect the ill-health of certain localities in Edinburgh with the Craigentinny meadows as its cause." With regard to the barracks at Piershill, which are stated to be "the most healthy in Scotland," there is certainly no injurious effect on the health of the soldiers from the irrigation of the fields. During the time that the cholera was epidemic at Leith and Edinburgh, "not a case occurred at Piershill Barracks (1865-66)." The same fact was observed at Barking: when the sewage of North London, where the cholera was prevalent, was poured over the irrigated fields, "no case of cholera happened at the farm or near it." At Norwood, Dr. Cresswell says that when the works were badly managed, "the irrigation fields *as a marsh* produced malarious diseases, and, in this case, intermittent fever amongst the children living in the vicinity."

Health of soldiers at Piershill barracks.

No cholera.

When a marsh, intermittent fevers.

Since that time he says: "I have been able in no case to trace any illness to these fields." In a school of more than thirty inmates, standing close to the fields, there has not been a single case of illness from preventible diseases. He concludes that, "when this system of sewage irrigation is *well managed*, the health of the inhabitants in the immediate vicinity is in no way influenced by it," and this on a deep clay soil. We find from the Ninth Report of the Medical Officer of the Privy Council, that at Worthing the irrigation works "do not cause any description of nuisance or injury to health." At Colney Hatch Lunatic Asylum (see Report of Dr. Brady's Committee), the irrigation "is certainly not injurious to health;" this being the opinion of the medical officers who visit it frequently.

When well managed, no evidence of disease caused by it.

The death-rate at Norwood, as a mere matter of fact, very considerably decreased after the establishment of the sewage farm there. In the three years before that took place (1865) it was over 18 per 1000; it then decreased, being as low as 12·07 in 1868, the population being then about 5000. At Beddington, too, where the farm is to the west of the town, the Medical Officer "can safely say that a continuance of west wind is always accompanied by a diminished amount of ordinary sickness in the district, and our annual mortality of the parish is generally below 20 in the 1000." (*Dr. Carpenter's Paper*, quoted p. 449.)

Diminution of death-rates near sewage farm.

Diminished sickness.

It is stated by Dr. Buchanan, in a special report to the Privy Council, that the health of the children living in the midst of the irrigated districts at Rugby, so far from suffering, has actually improved (*British Medical Journal*, 3d September 1870). In fact, the evidence appears to go to show that sewage fields, when properly managed, are *certainly* not injurious to health, and may possibly be even advantageous to it.

Improvement in health of children.

One of the strongest pieces of evidence connecting

Outbreak of dysentery.

sewage irrigation with disease, is the history of an outbreak of dysentery and diarrhœa at the Cumberland and Westmoreland Asylum in 1864 and 1865, an account of which, by Dr. Clouston, then medical officer, was published in the *Medical Times and Gazette*, 3d June 1865. The sewage—from which bath and lavatory water was withheld—was conveyed from the asylum to a close-vaulted tank 150 yards distant, where the solid matters were deposited. From this tank the sewage overflowed into "open cuts" in the land, which conveyed it to three acres of grass land to be irrigated. This plot of land was 300 yards from the female ward, and 350 yards from the male ward; it consisted of sandy soil lying on a subsoil of stiff brick clay—the whole area being under-drained. Before the outbreak, the sewage had been applied for two years to the land, but without any case of epidemic disease arising. Out of 250 inmates of the asylum, 31 were attacked with dysentery in little more than 13 months, and there were 20 deaths, but 15 of these were deaths of very old or paralysed patients. There were besides numerous cases of diarrhœa.

Under-drains obstructed.

Now, as to the condition of this irrigated land, we find that at the time of the outbreak there was a very offensive odour in its neighbourhood. Also we are told by Dr. Clouston that "the sand from the upper part of the field had completely obstructed the drains through the clay," so that the under-drainage was useless. We also find that "the field required better draining and levelling, and deeply trenching, so that the sewage might be spread over a larger surface and applied more scientifically, and that the extra liquid might drain away." This shows, to our mind, very clearly, that the sewage, which was very strong and probably putrid from being retained in the tank, became ponded on the irrigation plot, there to undergo further putrefaction—a morass of a most filthy description being formed. That such was in all probability the case is shown by the type of the disease, for Dr. Clouston says, "in its pathological appearances the dysentery bore a much greater resemblance to that form of the disease caused by or connected with malaria than to tropical dysentery." Even if, as Dr. Clouston believes, the dysentery and diarrhœa were due to the exhalations from the irrigated land, we fail to see that this outbreak proves any more than that sewage irrigation must be conducted on proper principles, for ponds of putrid sewage may undoubtedly produce disease.

Putrid sewage ponded on the irrigated land.

Sewage farms must not be filthy morasses.

Dr. Campbell, the present Medical Officer, who succeeded Dr. Clouston in 1873, informs us that "the sewage is still used freshly applied on the grounds of this Asylum. The ground irrigated has been considerably enlarged, and frequent and systematic change of sewage is enforced." Since 1874, when eight cases of enteric fever occurred, due to a contaminated water supply and defective drainage arrangements, there has been no case of dysentery or enteric fever in the Asylum, and Dr. Campbell writes that he is aware of "no disease or nuisance in any way arising from the distribution of the sewage as now effected in the Asylum."

Subsequent freedom from disease.

As far as the sanitary influence of sewage farming is concerned, the Sewage Committee of the British Association had returns from eight places where it is at work.

In no instance has any disease whatever been traced either among

No disease traced to the sewage farm.

the labourers on the farm or among the inhabitants in the vicinity, or among the cattle, to the sewage farm. In two instances it is reported that the health of the neighbourhood has improved, and in several that the land has very much improved in value, and the production of crops is much more certain." (*Report*, 1873, p. 449.)

Sanitary results of the sewage farm competition.

These accounts are very amply confirmed by the results of the inquiry into the sanitary aspect of sewage farming, given in the Report of the Judges on the Sewage Farm competition, 1879 (*Journal of the Royal Agricultural Society*, vol. xvi. part i. pp. 5, 6). From the returns of nine sewage farms, it appears that "the rate of mortality on an average of the number of years which these farms have been in operation, does not exceed three per thousand per annum." The judges observe that "this is a very low rate, but in all probability it may not be lower than would be found in an equal number of selected lives taken from an agricultural district. The results of the sanitary inquiry show that sewage farming is not detrimental to life or health." Horses and other live stock were found to be very healthy on all the farms examined.

Contagion among cattle.

It has been stated that the contagious diseases among cattle, and especially foot and mouth disease and rinderpest, will be spread by irrigation farming. The evidence hitherto obtained does not support this assumption; it rather goes to show that, as in the case of cholera, soil and growing plants really have the power of separating poisonous matters from the sewage, decomposing them, and rendering them harmless.

The following interesting case is recorded in the report of the engineer to the Croydon Board:—

Eleven head of cattle were affected with rinderpest; they were in a homestead at the head of the farm, and, at the time of the outbreak, forty head of cattle were pastured in the lower fields, and twenty cows, with twenty calves, were in the lower buildings. The whole of the drainage from the upper buildings passed over the adjoining land to the outfall; and although the cattle were pastured on the irrigated land, and were watered by the effluent water after it had passed over the land, not a single case of cattle-plague occurred amongst the animals on the lower portion of the farm. (See Dr. Alfred Carpenter's Paper on the *Physiological and Medical Aspect of Sewage Irrigation*, p. 45.) Rinderpest not propagated.

That the results of irrigation farming, properly carried out, may be a positive advantage to the health of neighbourhoods, has been shown to be possible in different instances. We need hardly point out that such might be expected to be the case from the luxuriant healthy vegetation which is supported upon sewage farms. The able researches of Dr. Daubeny, late Professor of Botany and Rural Economy at the University of Oxford (*Journal of the Chemical Society*, January 1867; or *Miscellanies*, by Charles Daubeny, M.D., F.R.S., vol. i. p. 55), have shown that the leaves of growing plants continually evolve ozone; and Mantegazza's more recent experiments have carried this further, and shown that during the oxidation of the essences of plants large quantities of ozone are produced, so large as to constitute a simple and valuable method for the preparation of this substance. Dr. Daubeny, indeed, had suggested that in some cases the coloration of the test-papers might be due "to the essential oil emitted by the flower," but he does not seem to have thought that the essential oil itself was capable of ozonising oxygen. The more important and more general observation is, however, that made by Dr. Daubeny, and he himself was perfectly aware of its importance: he says, speaking of "the uses which ozone subserves in the economy of nature":— Conclusion. Leaves of plants evolve ozone.

Purifying influence of ozone.

When we consider its remarkable oxidising properties, and the rapidity with which any organic matter, dead or living, undergoes a slow combustion in its presence, it seems reasonable to conclude that this principle is an important agent for destroying putrescent animal and vegetable matter by oxidation, and thus for restoring to the atmosphere its purity.

One of Dr. Daubeny's first memoirs confirmed the fact that plants restore more oxygen to the air by day than they consume by night, and determined "the description of solar rays which was most instrumental for that purpose." He exclaimed, when publishing his last discovery—

Means by which vegetable life purifies the atmosphere.

> Should I now have succeeded in establishing to the satisfaction of the scientific world that these same green parts of plants, at the very time that they are emitting oxygen, convert a portion of it into ozone, I might hope that these researches of my later years will serve appropriately to wind up those undertaken in my younger ones, by showing that vegetable life acts as the appointed instrument for counteracting the injurious effects of the animal creation upon the air we breathe, not merely by restoring to it the oxygen which the latter had consumed, but also by removing, through the agency of the ozone it generates, those noxious effluvia which are engendered by the various processes of putrefaction and decay.

Ozone in air over irrigated fields.

Dr. Alfred Carpenter, of Croydon, has (in his paper already referred to) given the results of his experiments on the presence of ozone in the air over irrigated fields; he says (*loc. cit.* p. 31)—

> I have found distinct traces of ozone in the Beddington fields, when there has been none in the town: it has been noted how very rapidly metals rust upon sewage farms,—this easily accounts for it. The surface of the meadows has been tested at various times in the very hottest days of July, when no ozone has been detected in the town, but it has been generally found present over the sewage grass, on those parts of the farm in which vegetation was most luxuriant.

Summary.

We have then good reason to expect that the utilisation of the sewage of towns on the land near them, while preventing the pollution of drinking-water and the spread thereby of cholera and typhoid fever, will at the same time maintain the purity of the atmosphere around and about the towns, and that the result will be, especially when combined with that produced by the increased demand for labour and the more plentiful supply of food, a diminution of the general death-rate.

THE ENTOZOA QUESTION.

The late Dr. Cobbold, in a *brochure* which he published in 1865, stated that he had great fear of the spread of entozoic disease by means of sewage irrigation. He said, speaking of the *Bilharzia*, a parasite which "infests the blood-vessels" of the natives of many parts of Africa, but which has occasionally been transported to England, so that its eggs may get into the sewage :—

> If without due consideration you adopt any one of the gigantic schemes now in vogue, you will scatter these eggs far and wide, you will spread them over thousands of acres of ground, you will place the larvæ in those conditions which are known to be eminently favourable for the development of their next stage of growth, you will bring the latter in contact with land and water snails, into whose bodies they will speedily penetrate ; and, in short, you will place them in situations where their yet higher gradations of non-sexual growth and propagation will be arrived at. After all these changes there is every reason to believe that they will experience no greater difficulty in gaining access to our bodies here in England than obtains in the case of those same parasites attacking our fellow-creatures whose residence is found in Egypt, in Natal, in the Mauritius, or at the Cape.

Apprehended danger from spread of entozoic disease.

And he asserted his "persuasion that the 'profuse distribution' of sewage tends both directly and indirectly to propagate no inconsiderable variety of parasitic diseases." He then went on to describe the various evils that may result from the abode of parasites within the human body.

Beyond all doubt Dr. Cobbold was the man above all others who had the best right to give an opinion upon any question relating to entozoa; and anything on that subject which comes from so great an authority must be considered with the utmost attention; but still we should endeavour to see how far facts justify so very important a conclusion, involving as it does a sweeping sanitary condemnation of the irrigation system.

Facts demanded.

Fresh excremental matters have been distributed in enormous quantities on land, for some thousands of years, in China and in other Eastern countries, and for many years around the city of Milan, where "it is admitted that the common mode of disposing of the fæcal matter is a nuisance, but that it is a source of disease is denied on all hands" (*Sewage of Towns Commissioners*). Sewage is, too, and has been for a long period, distributed over the lands around the same city. For more than two centuries sewage irrigation has been practised near Edinburgh, while during the past sixty years regular records have been kept of the particulars relating to it there, and for several years it has been employed around a certain number of English towns. Surely, with all these cases, some facts as to the increased prevalence, or otherwise, of hydatid disease in cattle, or of intestinal worms in man, in connection with sewage farms, have already been obtained. But not a single fact is advanced; it is not even hinted by any one that such diseases *are* more frequent where irrigation has been going on so long; and as to the *Bilharzia*, next to nothing is known of the migrations of its larvæ, while even in Africa "the disease is said to be more virulent in the summer months" (*Entozoa:* Cobbold). Despite our numerous communications with that country, this disease has not been known to spread

Instances of long-continued application of *fresh excrement* and sewage to lands.

either in England or in France, probably because our conditions of climate, etc., are not suitable either to the unknown "hosts" required by the larvæ, or to the transformations of the parasite itself.

We are not aware that any facts had been afforded by the experience at Edinburgh or elsewhere, in support of Dr. Cobbold's conjecture, that sewage farming will cause the spread of entozoic diseases; neither do we find that since the publication, in 1865, of the pamphlet referred to, any facts have been ascertained in its favour, unless it be the one stated by Dr. Cobbold in the discussion on a paper read by Dr. Letheby before the Metropolitan Association of Officers of Health (21st May 1870), that "a handful of large entozoa parasites had been taken from the Craigentinny meadows;" but he was at once answered by Mr. Holland, who "believed that the danger of spreading disease by the irrigation system was purely imaginary. Where was the evidence of *disease having been produced* where the system was adopted? He had made inquiries on the subject, and could find none. At Carlisle he asked whether the sheep had the rot, and was answered that they had not. At Edinburgh, cows had been fed with grass from the irrigated meadows for sixty or seventy years, but there was no evidence of the prevalence of disease among them," that is to say of entozoic disease. (The italics are ours.)

No facts brought forward.

Parasites found on Craigentinny meadows.

No evidence of entozoic disease at Carlisle or Edinburgh.

Two papers on this subject were communicated by Dr. Cobbold to the Association of Medical Officers of Health; they will be found in the *Medical Times and Gazette* for 28th January and 25th February 1871.

From a careful perusal of them, it clearly appears

No evidence of spread of entozoic diseases by sewage irrigation.

that up to that time there was yet no evidence whatever to show that entozoic disease had been caused in a single case either in an animal by feeding on sewaged produce, or in a man by eating the flesh of an animal so fed.

The objection that animals may be suffering extensively from entozoic disease without its being recognised during their lifetime, and that very few persons are qualified to recognise even measly meat when it is placed before them, entirely falls to the ground in the case of men, even if it be considered to hold good in that of cattle.

Had the communities which have been so long fed upon the flesh of animals fattened on sewage-grown produce been more troubled with entozoa than others, we should certainly have known of it. As a matter of fact, we do know where entozoic diseases are prevalent; we know that the population of Iceland is much troubled with one entozöon, that of Norway, Lapland, etc., with another, and that of the Punjab with a third; so that until it is shown that these diseases have been increased in men where sewage irrigation has been adopted, we have no sort of right to say that they will be; the facts are certainly on the other side.

Countries where they are prevalent.

Moreover, in the "Report on Measures adopted for Sanitary Improvements in India, from June 1869 to June 1870" (page 72), we find under the head "Entozoa in ration cattle," that "throughout the Punjab during 1868, 1038 head of cattle, or 6·12 per cent of those tendered for rations, were found infected." Although this has nothing to do with sewage irrigation, it shows that in some places at any rate where entozoic diseases are prevalent in cattle they are recognised, and that there would be no great difficulty in showing that the cattle on irrigation farms were more infected with them than other cattle if such were the case. This has not been done, although since 1865 attention has been drawn to the subject.

They are recognised in cattle.

But Dr. Cobbold stated that he considered the "A B C" process and the dry earth system to be, from the entozoic point of view, safer than sewage irrigation; on this head we may quote somewhat at length from the leading article on the subject which appeared in the *Lancet* of 4th February 1871:—

Other systems not less dangerous.

> Upon what evidence, then, does Dr. Cobbold state that one system is safe and the other dangerous? None whatever. There is not a single fact brought forward to show that the "A B C" process is capable of destroying parasitic ova, or that they perish when covered up in earth. On the latter point, all the analogies and facts are as yet against the inference. Parasitic diseases existed long before water-closets and sewers. It is well known that the ova can be dried without destroying their vitality; but there is no evidence to show that they are able to exist in sewage, or to resist the conditions of sewage transit. The more perfect the preservative action of the earth-closet, the more sure is the transmission of living ova to the land; whilst it seems to us at least as probable that the ova will survive the muck-heap as that they will fail to be destroyed by the sewer. Does Dr. Cobbold mean to say seriously that it is less dangerous to spread a field with manure than to irrigate it two or three times a year with sewage? In the one case the matter remains upon the surface, and adheres to the blades of grass; in the other, when properly administered, it at once sinks into the ground. In the one case the grazing cattle cannot fail to eat it; in the other it is beyond their reach. Dr. Cobbold has not adduced a particle of evidence to prove that the system of sewage irrigation is *more* likely to extend the spread of entozöotic disease than is that of putting manure directly on the land; whilst, on the other side, we have the evidence of Professor Christison, that he had never been able to refer a single case of parasitic disease to the sewage irrigation, so badly carried out at Edinburgh."

Liquid *v.* solid manure.

The vital powers of the eggs and larvæ of entozoa are well known to be, in many cases at any rate, very considerable indeed, but as far as the *Bilharzia* is concerned we have now some definite facts to go upon,

Bilharzia: new facts.

and we are bound to add that it was Dr. Cobbold himself who brought them to light. He said with regard to the larvæ of this formidable parasite (*Medical Times and Gazette*, 25th February 1871):—

Its larvæ perish in foul water.

The strength and vigour of the escaped larvæ appeared to depend upon the relative quantity and purity of the water in which the larvæ were immersed. In weakly-diluted urine they soon perished, and even also in water where only a small quantity of decomposed vegetable or animal matters had been introduced. On 16th August I placed about 1000 eggs in a quart of clean water, to which less than a drachm of urine had been likewise added. In forty-eight hours not a single living embryo could be found. In fact, I subsequently ascertained that I could not keep the embryos alive for twenty-four hours in any water in which I had accidentally or otherwise introduced the smallest trace of mucus, blood-corpuscles, urinary crystals, or decomposing matter of any kind. All sorts of re-agents speedily killed the larvæ, etc.

As regards *Bilharzia*, therefore, the above data, now publicly brought forward for the first time, undoubtedly appear to favour the notion that little harm can result from sewage distribution, so far at least as parasitism is concerned.

Question of vitality of larvæ in sewage.

Whether the eggs and larvæ of other entozoa do arrive in a living state on sewage farms, we do not yet know, but if anything is likely to be injurious to organisms whose natural habitat is the acid excretion of the human intestines, we should suppose that it would be immersion in a liquid containing much urine, which so soon becomes alkaline from the conversion of the urea into carbonate of ammonia. We think with Dr. Cobbold, that "how long they are able to retain their vitality when dispersed by sewage and other means is a point worthy of further inquiry;" and as one fact towards the solution of this question, we quote the following passage from the Report of the British Association Committee, to which we have already alluded (*B. A. Report*, 1870, p. 52):—

Some specimens of sewage-grown rye-grass, carrots, turnips, onions, beet, and lettuce, from Breton's farm, were sent to Mr. M. C. Cooke, M.A., for examination, with a view to the possible discovery of entozoic eggs or larvæ. He states that "the rye-grass was mouldy, but only from such moulds as are the result of decay from the damp grass having been kept several days enclosed;" and he summarises the results of his examination of the vegetables as follows:—"I find nothing whatever to report against any of them. They all seem to me in excellent order, and free from parasitic insects, or from fungi of any kind."

Sewage-grown produce free from objectionable organisms.

Dr. Cobbold informed us that he thought that the plain-water irrigation practised in the Punjab may, on account of the dirty habits of the natives, have something to do with the prevalence of entozoic disease there: we submit that the filthy practices alluded to (the deposition of excreta indiscriminately about the fields, around the villages, etc.) are in so many countries the great cause of the spread of such diseases, that there is no reason for supposing that the irrigation has anything to do with it.

Plain water irrigation.

Some further experiments made by the British Association Committee, with the view of inquiring into the possibility of the distribution of entozoic disease by means of sewage irrigation, have an important bearing on this question. Some "slime and mud" from the bottom and sides of carriers at Earlswood farm was submitted to Mr. M. C. Cooke, M.A., for examination, who found "that it contained life of various kinds, especially annelida, but did not detect any entozoic larvæ." The existence of this slime at the bottom of the carriers here was attributed by the Committee "to the fact that the subsoil is kept in a saturated condition by the want of under-draining;" and they were of opinion "that when land is thus saturated with sewage, certain atmospheric conditions exist which may be attended by malaria more or less injurious to health." (*Report*, 1871, p. 182.)

Examination of slime and mud from carriers.

Subsoil saturated.

In order, if possible, to throw further light on the

Carcass of ox fed on sewage-grown grass, free from internal parasites.

subject, Dr. Cobbold was requested by the Committee to examine the carcass of an ox, which had been fed for two years on sewage-grown grass at Mr. Hope's farm, near Romford. Dr. Cobbold reported "the perfect freedom of that animal from internal parasites of any kind." He attributed this marked negative result to the following circumstances :—

Circumstances likely to produce this result.

"First, the animal did not graze on the farm, but was fed exclusively upon vegetable products cut and carried from the land." "Secondly, the porous nature of the soil and subsoil alike would rapidly carry off the sewage, and thus ensure the passage of parasitic germs into the soil itself." Thirdly, he noticed on the irrigated portions of the farm "a remarkable absence of those molluscan and insect forms of life which frequently play the part of intermediary bearers." Fourthly, the only molluscs he detected were "examples of *Lymneus pereger;*" these were obtained from a small pit of water to which the sewage had no access, and when examined after death "were not found to contain any cercarian larvæ." Fifthly, the flaky vegetable tufts collected by him from the sides of the furrows occupied by sewage currents "consisted chiefly of *Batrachospermum moniliforme*, in the filaments of which were numerous active free nematodes, but no ova of any true entozoon." "Sixthly, the sewage had a strong smell of beer, suggesting the presence of sufficient alcohol to destroy the vitality of ordinary parasitic germs, though it was abundantly manifest that the free nematodes had suffered nothing in consequence." Dr. Cobbold concludes his Report as follows :—

Efficient mode of examination.

As some guarantee for the efficient manner in which the carcass of the ox was examined, I may mention that the superficial muscles, with their associated areolar and aponeurotic coverings, were particularly investigated, portions of certain muscles, such as the scaleni and sterno-maxillaris, being dissected through and through. All the viscera were likewise scrutinised, especially the brain, lungs, liver, bladder, kidneys, paunch, reed, cœcum, and other natural divisions of the intestinal canal. The animal was not excessively fat, whilst its muscles were well developed and of a deep carneous lustre.

The remarks by the Committee on the above Report are as follows:—

With regard to the examination of the carcass of the ox, which had been fed for twenty-two months on sewaged produce at Breton's farm, those members of the Committee who were present and examined it with Dr. Cobbold concur in his statement as to its perfect *freedom from internal parasites of all kinds;* and they can also subscribe to most of his observations with regard to the possible reasons for this immunity. They wish especially to draw attention (1) to the fact that on this farm there is "a remarkable absence of those molluscan and insect forms of life which frequently play the part of intermediary bearers" to entozoal larvæ: it would appear that the sewage drives these creatures away or kills them;* and (2) to the composition of the "flaky vegetable tufts" collected from the sides of the carriers; these contained "numerous active free nematodes, but no ova of any true entozoon." Remarks by the Committee.

But the Committee cannot support the opinion expressed by Dr. Cobbold, that the strong smell of beer which the sewage had (caused of course merely by hop waste) would suggest "the presence of sufficient alcohol to destroy the vitality of ordinary parasitic germs," as the quantity of alcohol which would be necessary for this purpose in so large a bulk of sewage would be enormous, and especially as, as Dr. Cobbold says, "it was abundantly manifest that the free nematodes had suffered nothing in consequence."

It appears, then, that as far as this one case goes (and it is certainly as conclusive as a single case could possibly be), there is no evidence that entozoal forms of life are to be found upon the farm at all, in any stage of their existence, or in the flesh of an animal fed exclusively for twenty-two months on sewaged produce grown on the farm. (*Report*, 1871, Appendix B., pp. 189, 190.) No entozoal forms of life to be found.

Since the date of that report no facts have been recorded connecting entozoic diseases with sewage irrigation.

We see no reason, therefore, to alter our opinion that it has not yet been shown that sewage irrigation Summary.

* With this must be associated the observations recorded by the Committee on the destruction of wire-worms by sewage (p. 395).

has ever increased the amount of entozoic disease in men or cattle, still less that it is likely to do so to a greater extent than any other method of utilising human excrement; and even were this shown to be the case, the danger would be to a great extent obviated by some such preliminary treatment, with a view to the separation of the suspended matters, as we have already insisted upon.

APPENDIX

TREATMENT AND UTILISATION OF MANUFACTURING REFUSE

MANY of our rivers, especially in the north of England and in Scotland, besides being polluted by the sewage of towns on their banks, are also contaminated by the refuse from factories of various kinds. This subject is so important and the interests involved in it are so large that it requires separate consideration.

Of the *Worth* (below the town of Keighley), a tributary of the *Aire*, one witness, before the Rivers Pollution Commission, said:—

State of the Worth.

> Formerly trout were very plentiful in the stream, but now no living thing can exist except rats, which feed on the dead carcases of animals thrown in. The river, for more than half a mile above my works, is very seriously polluted by town sewage and refuse from manufactories and works; and in the summer the stench is so bad that the smell is perceptible for more than half a mile off. (Third Report, 1868, p. 4.)

The *Bradford Beck* is, above the town, clear (although not altogether in an unpolluted condition), and "appears to abound with fish" (p. 5).

Polluted state of various rivers.

> In passing through Bradford it receives, besides the sewage of 140,000 people, the drainage and refuse of numerous factories.
>
> The *Bradford Beck* as it leaves the town is a black, filthy, and offensive stream; even above the sewer outfall it was, at the time of our inspection, emitting offensive gases, and could scarcely be distinguished in appearance from the sewage itself.

The sewage of Leeds, to the amount of 11,000,000 gallons daily, enters the *Aire* (p. 7).

Twenty years ago the river was comparatively clean; it is now a black and greatly polluted stream.

Both the river and its affluents flowing through the town are, especially in time of drought, very foul, and consequently prejudicial to the health and comfort of the inhabitants.

At a distance of about ten miles below Leeds, and immediately above Castleford, the *Calder* joins the *Aire*. The inhabitants complain of the stench and filth brought down to them by both rivers. At the weir beside the Aire and Calder corn-mill here, not only the water, but the foam upon it, was black at the time of our inspection; and the miller and his men complained of the frequent nausea which they suffered from the sickening filthy stench to which they were continually subjected (p. 8).

Nausea caused by effluvia from river.

But it may perhaps be thought that such water would never be used for drinking purposes: this idea will soon be dispelled. The *Calder*, already somewhat polluted, "receives the water of the *Hebble*, a stream which brings down to it a very filthy contribution from the town of Halifax." Farther on it is joined by the *Colne*, a "foul stream," which has been so polluted by Huddersfield as to have more than doubled its proportions of organic carbon and organic nitrogen, and to be "said to be a source of ill-health and discomfort;" and about six miles lower down "it receives the water of a small beck, an extremely filthy stream, which brings down the drainage of Batley and Dewsbury." This river receives, lastly, the sewage and "many kinds of liquid refuse" of Wakefield, a town of 26,000 inhabitants, and is so discoloured that at times it may be used as ink, and the Commissioners actually give a facsimile of a memorandum made with it, "the pen having been dipped in the river water immediately below the outfall sewer of the town, at a time when there was an unusually filthy discharge from it." Below the town "the river was turbid, and of a dark brown colour; an oily film floated on the surface, and the water emitted a mixed odour of sewage and gas tar." It will scarcely be credited that "*at a point somewhat below this, 'about a mile below the main sewer outlet,' the water supply of Wakefield is taken from the river*" (pp. 11 and 12. The italics are ours.) Of this water "a volume of 1,000,000 gallons is daily pumped from the river."

An extremely polluted river.

Supplies drinking water.

We should think that no one will be found to disagree with the Commissioners when they say:

Remarks of Commissioners.

> Although "the water is filtered by a patent process," it is difficult to conceive anything more disgusting and dangerous to health than a populous community thus systematically, and by an elaborate and costly arrangement of reservoirs, pumps, filters, and distributory apparatus, drinking its own filtered sewage, taken from a stream in a black and putrescent condition (p. 39).

The water as supplied to the town was examined on two occasions, at an interval of a year. It "was chemically less contaminated than might be expected, yet on both occasions it contained a large proportion of nitrogenous organic matter. It was of a greenish yellow colour, and on one occasion very turbid."

This case speaks for itself: it would be difficult to find one which would do so more eloquently. Is it necessary to show that people would be more healthy if they drank pure water? Plenty of proof of this has been given in chapters ii. and vii. Here is another case:—Dewsbury, Batley, and Heckmondwike are now supplied with unpolluted water "from about 2000 acres of gathering ground."

Advantages of unpolluted water:

> The authorities in all three towns concur in stating that the health of the people has improved since the introduction of this mountain water in the place of the previous supplies from polluted rivers and wells (p. 38).

Need any other reasons be adduced for purifying the rivers than that their state is detrimental to health? Let us hear what the manufacturers at Leeds say on this point (p. 7):—

of clean rivers.

> If the river were rendered clear and colourless, it would be a direct money value to us of from £60 to £70 a year.
>
> If the river were rendered clear and colourless, it would be of considerable money value to us, but we cannot give the amount.
>
> If the river from which we might derive a supply of water were rendered clear and colourless, it would be a direct money value to us of £100 a year.

And so on. In fact the Commissioners came to the conclusion that on the whole "the foul condition of these rivers is really one of the heaviest taxes which manufacturing industry has to bear."

These rivers must be cleansed by intercepting the foul liquids—not only the sewage, properly so called, but the refuse from manufactories, which is in some instances very valuable. Thus the waste liquor discharged into the Severn from the flannel works at Newtown contains in 100,000 parts no less than 1733·4 of suspended organic matters, 446·353 of dissolved organic carbon, 91·185 of dissolved organic nitrogen, and 80·012 of ammonia (p. 25).

Waste liquors from manufactures.

The composition of the waste liquor from flannel washing proves it to be, in the case examined, a most valuable manure, one hundredweight of it being worth, for this purpose, more than one ton of London sewage. The discharge of such liquors into rivers is a reckless waste.

The Commissioners were of opinion that—

Manufacturing refuse with certain exceptions may be discharged into the sewers.

For populous places which are also seats of manufacture, it would generally be possible, without materially complicating the sewage problem, to allow the fluid refuse of industrial processes, with few exceptions, to pass into the sewers to be disposed of as common sewage; the special exceptions which are named being the refuse of workers in metals, and of manufacturers of gas, paraffin oil, pyroligneous acid, and animal charcoal; that subject to some such exceptions as these and to proper regulations, the discharge of fluid industrial refuse into sewers would generally not render the sewage more difficult of use, and would in some cases, in respect of certain contained refuse matters, greatly increase the agricultural value of the sewage. (*Report of the Medical Officer of the Privy Council and Local Government Board*, No. II., 1874, p. 30.)

The important question then arises, if these liquids may not, any more than sewage, be turned into rivers, what is to be done with them?

Several remedies are proposed in exceptional cases, but the only one which admits of almost universal application is *irrigation* on land, or, where this is impracticable, *intermittent downward filtration* through a sufficient depth of soil. When these foul liquids have been so treated the effluent water was so purified as to be admissible into a stream.

Purified by irrigation.

But if these liquids are purified by filtration, or by irrigation, will it be advantageous to irrigate crops with them? This has been tried in a very rough and ready manner at several mills; at one near Shepley it was found that the produce of some old grass land was increased by irrigation with "the soapy, greenish, greasy mill drainage," but that "the coarser grasses, strengthened by the irrigation, had killed the finer, and the quality of the produce was injured" (p. 31).

These liquors, therefore, may not be suitable for irrigation if used alone, except perhaps in the case of "strong and rapidly growing plants." It is probable that the organic matters and ammonia are contained in them in too high a proportion as compared with the potash and phosphates; but from their composition there can be no doubt that "their utility for this purpose would be much augmented if they were previously mixed with several times their volume of town sewage" (p. 30). Where this has been done the result has been satisfactory. Better not utilised alone.

At Cullingworth, near Bingley, the drainage of a large mill—mingling here, however, with that of the village—flows on to some hill-side grass land, and produces a large growth of grass before finding its way into the stream. The result here, if not attributable wholly to the fertilising effect of dirty wool washings, at any rate proves that such dirty waters, with the spent liquors from dye-works, may be discharged into ordinary house sewage without injury to its value as manure" (p. 31). May be mixed with sewage.

Where irrigation is impracticable, intermittent downward filtration through soil, or through banks of cinders and ashes, is shown to be quite competent to purify these foul liquids. In one case where the latter plan was pursued "the effluent water was colourless and nearly free from suspended matter," while "in respect of soluble polluting ingredients it did not transgress our standards of purity" (p. 34). Filtration through soil or ashes.

It seems probable that "the addition of a slight excess of lime to the liquid before filtration" would hasten the nitrification of the organic matters and ammonia, and so prove advantageous.

With regard to intermittent downward filtration for the purification of sewage, the Commissioners say:—

Whereas 100 acres or more might be needed to cleanse, certainly to profitably utilise, the drainage of a town of 10,000 people by means of irrigation, it would need but 3 acres of a porous medium, 6 feet Comparison of irrigation with filtration.

deep, worked as an intermittent filter, to oxidise, and therefore purify, the drainage water of such a town, provided the mass of earth through which it percolated were frequently and effectually aërated, and the foul liquid were so added that every part of this aërated filter had its equal share and equal interval of aëration (p. 51).

Nuisance of filtration; how lessened.

The "formidable nuisance" which would possibly be created by this immense filter would be greatly lessened by the separation of the suspended matters by precipitation, "whilst it would probably reduce by one-half the size of the filter necessary for cleansing a given volume of sewage."

Where filtration may be adopted.

This alternative method of dealing with the sewage difficulty may therefore be adopted with advantage by towns in steep and narrow valleys, where a sufficient area of land for irrigation cannot be obtained below the sewer outfall, and where the cost of pumping on to higher lands would be excessive (p. 51).

But filtration through soil should only be resorted to where it is absolutely impossible to procure land for irrigation on account of the natural conformation of the country; for, as the Commissioners say (p. 51)—

It is the great advantage of the irrigation remedy for this class of river pollutions that their filth is not merely destroyed, but converted into wholesome food. Valuable marketable products are obtained, and thus the expense of the process may be recovered.

General results.

The important point brought out by this Report is, then, that the same method of purification which is alone capable of dealing with town sewage, may be employed in the case of these refuse liquors; that although it may not be advantageous to use them alone for irrigation, yet they may be mixed with the town sewage, and the whole purified and utilised together; that is to say, that the water-carriage system combined with irrigation, or with intermittent downward filtration through soil, is capable of treating all such refuse liquors as do not contain anything injurious to crops; in other words, it can remove, purify, and (in the case of irrigation) utilise all liquids containing putrescible organic matters, leave an effluent water which does not transgress the proposed standards, and so prevent the pollution of the rivers.

The researches of the Rivers Pollution Commissioners induced them to suggest that the following liquids be deemed polluting and inadmissible into any stream :—

(*a*) Any liquid . . . containing, *in suspension*, more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid. Definition of polluting liquids.

(*b*) Any liquid containing, *in solution*, more than two parts by weight of organic carbon, or ·3 part by weight of organic nitrogen, in 100,000 parts by weight.

(*c*) Any liquid which shall exhibit by daylight a distinct colour when a stratum of it 1 inch deep is placed in a white porcelain or earthenware vessel.

(*d*) Any liquid which contains, *in solution*, in 100,000 parts by weight, more than two parts by weight of any metal except calcium, magnesium, potassium, and sodium.

(*e*) Any liquid which in 100,000 parts by weight contains, *whether in solution or suspension*, in chemical combination or otherwise, more than ·05 part by weight of metallic arsenic.

(*f*) Any liquid which, after acidification with sulphuric acid, contains, in 100,000 parts by weight, more than one part by weight of free chlorine.

(*g*) Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition either of sulphuretted hydrogen or of a soluble sulphuret.

(*h*) Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1000 parts by weight of distilled water.

(*i*) Any liquid possessing an alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

(*k*) Any liquid exhibiting a film of petroleum or hydrocarbon oil upon its surface, or containing, *in suspension*, in 100,000 parts more than ·05 part of such oil. (*Fifth Report, R. P. C.*, p. 49.)

The Commissioners were of opinion that the above standards may be safely qualified by the following proviso :—"Provided always that no effluent water should be deemed polluting, if it be not more contaminated with any of the above-named polluting ingredients than the stream or river into which it is discharged." Proviso.

The Rivers Pollution Prevention Act, 1876, made it illegal to discharge into any stream :—

1. The solid refuse of any manufactory, manufacturing process, or quarry ; or any rubbish or cinders ; or any other waste or putrid solid matter. Solid manufacturing refuse.

Sewage matter.

2. Any solid or liquid sewage matter, unless the channel by which such sewage matter is discharged was used, constructed, or in process of construction at the date of the passing of the Act, the best practicable and available means being in use to render the sewage matter harmless.

Extension of time.

The Local Government Board are empowered to grant extension of time to any sanitary authority, who at the date of the passing of the Act were discharging sewage into any stream, for the purpose of enabling such authority to adopt the best practicable and available means to render the sewage harmless.

Liquid manufacturing refuse.

3. Any poisonous, noxious, or polluting liquid, proceeding from any factory or manufacturing process, unless the channel by which such liquid is discharged was used, constructed, or in process of construction at the date of passing of the Act; or if the channel is a new one, was constructed in place of the old one, and has its outfall at the same spot, the best practicable and reasonably available means being in use to render the polluting liquid harmless.

Mining refuse.

4. Any solid matter, or any poisonous, noxious, or polluting solid or liquid matter from any mine, other than water raised from such mine, unless the best practicable and reasonably available means have been adopted to render such liquid harmless.

Manufacturing refuse may be excluded from sewers.

A local authority cannot be compelled to admit into its sewers any liquid from manufactories which would injure the sewers, or prejudicially affect the disposal by sale, application to land or otherwise, of the sewage matter, or would from its temperature or otherwise be injurious in a sanitary point of view; or when the sewers are only sufficient for the requirements of the district.

The definitions are :—

Definition of stream.

"Stream" includes the sea to such extent, and tidal waters to such point, as may after local inquiry, or on sanitary grounds, be determined by the Local Government Board. Save as aforesaid, it includes rivers, streams, canals, lakes, and watercourses, other than watercourses at the passing of this Act mainly used as sewers, and emptying directly into the sea or tidal waters, which have not been determined to be streams within the meaning of this Act by such order as aforesaid.

Solid matter.

"Solid matter" shall not include particles of matter in suspension in water.

"Polluting."

"Polluting" shall not include innocuous discoloration.

THE DISPOSAL OF THE SEWAGE OF LONDON.

From the conclusions and recommendations of the Royal Commission on Metropolitan Sewage Discharge given below (see p. 481), it will be seen that in their opinion the present method of disposal, viz. that of turning the crude sewage into the Thames at Barking and Crossness, must be given up, and they state that the evils produced by it "imperatively demand a prompt remedy." They also say that "it is neither necessary nor justifiable to discharge the sewage of the Metropolis in its crude state into any part of the Thames," and "any part of the Thames" would appear to be "from the Nore upwards." (*Second Report*, p. 63.)

The crude sewage of the Metropolis must not be discharged into any part of the Thames.

As to the treatment of the sewage, they say that "some process of deposition or precipitation should be used to separate the solid from the liquid portions of the sewage," that this process must be conducted without nuisance, and that the sewage water, after such deposition or precipitation of the suspended matters, might be allowed to escape into the river at the present outfalls "as a preliminary and temporary measure," but that for a permanent solution of the difficulty, it would be necessary to further purify the liquid portion; and, they add, "this, according to the present state of knowledge, can only be done effectually by its application to land." They anticipate, and with good reason, that "suitable land in sufficient quantity and at reasonable cost cannot be procured near the present outfalls," and they therefore recommend "that the sewer liquid, after separation from the solids, be carried down to a lower point of the river, at least as low as Hole Haven, where it may be discharged;" but, they add, "it may be found that the separating process can be effected more conveniently at the new than at the present outfalls?" It is, therefore, quite clear that the simplest way of overcoming the difficulty would be by conducting the sewage of the southern side across the river, and by the construction of an outfall sewer from Barking to Hole Haven—a distance of 18 miles—of capacity sufficient to take the whole of the Metropolitan Sewage. Any attempt to purify the sewage at the sites of the present outfalls, except by filtration through land, must be regarded as a mere makeshift, and quite inadequate to deal permanently with the problem.

Treatment of the sewage.

Permanent solution of the difficulty.

Construction of outfall sewer to Hole Haven.

And yet the Metropolitan Board of Works have now resolved to undertake a scheme of this nature, viz. chemical

Scheme of the Metropolitan Board of Works.

precipitation of the sewage at the present outfalls, and have even advertised for tenders for vessels of special construction capable of holding a thousand tons of the semi-liquid sludge, which is to be taken out to sea, and discharged under water.

As an experiment unsatisfactory.

If this scheme is merely regarded as an experiment it is unsatisfactory, for if it gives way, as it must do in course of time, to the only undertaking which in the opinion of the Commissioners is likely to satisfy sanitary requirements, viz. the conveyance of the whole of the sewage to Hole Haven, there to undergo purification by precipitation or by treatment on land, the large outlay of public money required for the construction of the necessary tanks and machinery at the present outfalls may be wasted, for it will probably be considered better to convey the sewage untreated to Hole Haven, where the disposal of the sludge will present much less difficulty than at the present outfalls, and should it be decided to treat the sewage in accordance with the Canvey Island Scheme, presently to be described, there would be no use whatever for the precipitating works which are to be erected at the present outfalls.

Probable waste of public money.

Remarks.

We can only conclude that the Metropolitan Board do regard their present scheme as a permanent measure, and in so doing they will be setting at nought the conclusions and recommendations of the Royal Commission specially appointed to inquire and advise on the whole subject, composed of men most thoroughly competent to do so, and with whose recommendations the great body of scientific opinion in this country is entirely agreed.

Sir Joseph Bazalgette's scheme.

Sir Joseph Bazalgette, in his evidence before the Royal Commission, recommended that all the districts round London, comprising those in the Lee valley and in the lower Thames valley, should be included in a scheme for the removal of the London sewage lower down the river. The scheme he proposed was to carry the sewage of the south of London under the river from Crossness by means of an inverted siphon, and to connect this with a new outfall sewer to be constructed from Barking to Thames Haven, this outfall sewer to be

17 feet 6 inches in diameter, which would allow for an increase of 50 per cent over the maximum flow. It would be capable of discharging 40,000 cubic feet a minute, with a fall of 1 foot per mile, and a velocity of flow varying from $1\frac{1}{2}$ to $1\frac{3}{4}$ mile an hour. The sewer would be constructed mostly in tunnel, and take a straight line down to Thames Haven. Here the sewage would be received in reservoirs capable of holding ten hours' flow, and would then be discharged into the river at ebb tide in its crude state. This sewer would be capable of taking the sewage of 5,200,000 people from the Metropolitan area, and of 1,800,000 from the suburban area. The cost of its construction would be £4,000,000, and the cost of pumping and other items would amount to £41,000 a year, allowing for an increase of 30 per cent on the population of London, the Lee valley, the Thames valley, and adjoining towns. The rateable value of all these amounts to £32,000,000, so that the cost would be equal to a rate of $1\frac{3}{4}$d. in £1. Cost.

This scheme is no doubt a good one as far as it goes, but we have seen that the Royal Commissioners condemned the discharge of sewage in its crude state into any part of the Thames, and this is what would be done if the scheme of the Engineer to the Metropolitan Board of Works were adopted, without some method of purification of the sewage before its discharge into the river. Scheme inadequate.

A scheme for the treatment of the Metropolitan sewage on land has been put forward by Lieut.-Col. A. S. Jones and Mr. Bailey Denton, and is thus described in *Engineering* (21st August 1885):

Canvey Island Scheme.

Within about a mile of Thames Haven is a large piece of land reclaimed from the river and called Canvey Island. It is surrounded with banks, and its surface is of one general level, with only such natural hollows as have been formed by the off-flow of the surface water. The height of the land is about 8 feet above ordnance datum, or 9 feet 6 inches above low water mark, while the surrounding banks are 9 feet higher. The area is about 4000 acres, while the population is only 300, occupying 51 timber-built dwellings besides the vicarage. The whole island forms a natural tank capable of holding, without overflow, about 10,000 million gallons of liquid, supposing it were turned to the purposes of a reservoir, which, however, is not proposed. More than

Area of the island.

three-quarters of the whole of this island have been secured by Lieut.-Col. Jones and Mr. Bailey Denton.

Offer by Lieut.-Col. Jones and Mr. Bailey Denton.

These gentlemen have made a definite offer to take the whole discharge of the new sewer (proposed by Sir Joseph Bazalgette), to precipitate and deposit the solids, filter the liquid and discharge it practically pure into the river, for an annual sum of £110,000, of which £66,000 is for working expenses, and £44,000 is for interest and sinking fund on the land and plant. At the end of forty years they propose that the whole island, with the entire plant, shall be delivered up to the Board of Works as its property without further charge. The plan of operations is not definitely settled as yet, but it will probably be on the following lines. The entire land will be underdrained to a depth of 4 feet 6 inches, and three main conduits branching off the end of the proposed Board of Works sewer will traverse it lengthwise, with their inverts level with the surface, and the crowns of the arches level with the top of the surrounding banks. Around these conduits there will be constructed by means of earthen walls, a large number of rectangular basins or tanks, the whole covering an area of 1680 acres. These tanks are to be of two kinds, depositing tanks and effluent water tanks. The former are each 15 acres in extent and are arranged in groups of four. Through the centre of each group there runs a conduit with necessary appliances for directing the flow of the sewage. Calling the four tanks A, B, C, and D, the sewage will, in the first instance, be turned into A. It will fill that and flow over into B, then into C, and finally into D. In A it will deposit the heaviest portion of its solid impurities, the process being aided by milk of lime previously added; the less heavy portion will fall into B, a still lighter portion into C, and the lightest of all into D. By this time the liquid will be clear of suspended matter, and will flow over into the effluent water tank. It will be understood that, as there are three conduits, three or more groups of tanks will be in operation at once.

Probable plan of operations.

Depositing tanks and effluent water-tanks.

After a time the order of flow will be altered, B becoming the first tank, and the others following in the order C, D, and A. Next C becomes the first tank, and so on; the result being that all the tanks are filled at the same rate, and with a uniform composition which is arranged in strata. When a considerable bed of sludge has accumulated in a set of tanks they will be thrown out of action and the sludge dried. This will be effected simultaneously both from above and below. The under drains will allow the water to flow away beneath, while that above will be removed by decantation from time to time as it separates itself from the mud, until the whole shrinks into a compact mass, when the tanks will be put into service again. The daily deposition will be equal to a layer of from 5 inches to $7\frac{1}{2}$ inches thick over an acre, consequently the available depth of 100 inches could be filled in 13·3 days at the soonest. But supposing three groups of tanks, that is 180 acres, were in use, the level would only rise at the rate of ·04 inch per day.

Under-drains.

The effluent water will be purified by passage over and through the land which surrounds the tanks. It will be distributed over the soil; much of it will sink through it to the drains, while the remainder will pass down through beds of sand and broken shells, and the whole will find its way into reservoirs from which it can be discharged for the last three hours of the ebb, and, if necessary, the first three of the flood tide. The water which does not get below the surface will be caught in a high level reservoir and discharged from that.

Purification of the effluent water.

The present dry-weather sewage daily discharged by the Metropolis is taken at 150 million gallons, and it may probably increase to 200 million gallons. An area of 90 acres will receive a day's discharge without overflow, while the solid deposit, including the lime, will amount in a year to sufficient to fill 30 acres of the island up to the level of the banks. The area mentioned above will therefore require fifty years to fill, and an additional piece which adjoins it will suffice for twenty-five years more. Then there is Bower's marsh available, and other land which can easily be reclaimed, and which when raised above high water mark will become valuable.

Volume of sewage to be treated.

Level of the land raised by the deposition of sludge.

The nature of the soil of the island is a river mud or alluvium, absorbent and permeable, and admitting of under-drainage. The lime necessary for precipitating the sewage could be prepared in kilns from the chalk obtained from the neighbouring hills on both sides of the river.

As the Reports of the Royal Commission on Metropolitan Sewage Discharge have been largely referred to in these pages, and are, moreover, of the very greatest interest, dealing as they do with the most difficult problem of sewage disposal ever presented to the world, we have considered it desirable to insert the conclusions and recommendations of the Commissioners, which are contained in their First and Second Reports.

CONCLUSIONS—FIRST REPORT.

1. That the works of the Metropolitan Board, for the purpose of carrying the sewage of London to the respective outfalls at Barking Creek and Crossness, have been executed in a highly creditable manner, and have been of great benefit to the Metropolis.

2. That the storm overflows allow the occasional discharge into the river within the Metropolis of considerable quantities of solid fæcal matter accumulated in some of the sewers; but this has not caused, under present circumstances, serious damage or offence.

3. That the sewage from the northern outfall is discharged partly over the foreshore, and not as was originally intended, "through sub-

merged pipes terminating below low-water mark ;" this arrangement increasing the risk of nuisance from the discharge.

4. That the discharge of the sewage in its crude state, during the whole year, without any attempt to render it less offensive by separating the solids or otherwise, is at variance with the original intention, and with the understanding in Parliament when the Act of 1858 was passed.

5. That the sewage discharged from the main outfalls becomes very widely distributed by the motions of the water, both up and down the river, being traced in dry seasons through the Metropolis and almost as high as Teddington. And that it oscillates for a long period before getting finally out to sea.

6. That the dilution of the sewage by the land and sea water, aided by the agitation produced by the various motions in the river, effects a partial purification of the sewage by oxidation. And that this purification is carried further by the action of animal and vegetable organisms.

7. That the sewage, which becomes distributed to the higher and to the lower portions of the river, thus gradually loses its offensive properties. The limits above and below the outfalls where this purification becomes efficient, vary with the meteorological conditions ; but it may be stated that, in general, above Greenwich and below Greenhithe the river does not afford ground for serious complaint.

8. That between these limits the effects of the sewage discharge are more or less apparent at all times.

9. That in dry seasons the dilution of the sewage is scanty and ineffective, especially at neap tides.

10. That it does not appear that hitherto the sewage discharge has had any seriously prejudicial effect on the general healthiness of the neighbouring districts. But that there is evidence of certain evil effects of a minor kind on the health of persons employed on the river ; and that there may reasonably be anxiety on the subject for the future.

11. That in hot and dry weather there is serious nuisance and inconvenience, extending to a considerable distance both below and above the outfalls, from the foul state of the water consequent on the sewage discharge. The smell is very offensive, and the water is at times unusable.

12. That foul mud, partly composed of sewage matter, accumulates at Erith and elsewhere, and adheres to nets, anchors, and other objects dropped into it.

13. That sand dredged near the outfalls, which used to be obtained in a pure state, is now found to be so much contaminated with sewage matter as to be unusable ; compelling the dredgers to go farther away.

14. That for these reasons the river is not, at times, in the state in which such an important highway to a great capital carrying so large a traffic ought to be.

15. That in consequence of the sewage discharge fish have dis-

appeared from the Thames for a distance of some 15 miles below the outfalls, and for a considerable distance above them.

16. That there is some evidence that wells in the neighbourhood of the Thames are affected by the water in the river; and, although there is no proof of actual injury due to the sewage, that anxiety may be felt on that point.

17. That there is no evidence of any evil results to the navigation of the river by deposits from the sewage discharge; but that this discharge adds largely to the quantity of detritus in the river, and so must increase the tendency to deposit.

18. That the evils and dangers are likely to increase with the increase of population in the districts drained.

19. That it is desirable we should inquire further "what measures can be applied for remedying or preventing" the evils and dangers resulting from the sewage discharge.

CONCLUSIONS AND RECOMMENDATIONS—SECOND REPORT.

1. Our opinion of the evils described in our First Report, as resulting from the present system under which sewage is discharged into the Thames by the Metropolitan Board of Works, is much strengthened, and we believe these evils imperatively demand a prompt remedy.

2. We are of opinion that it is neither necessary nor justifiable to discharge the sewage of the Metropolis in its crude state into any part of the Thames.

3. We are of opinion that some process of deposition or precipitation should be used to separate the solid from the liquid portions of the sewage.

4. Such process may be conveniently and speedily applied at the two present main outfalls.

5. The solid matter deposited as sludge can be applied to the raising of low-lying lands, or burnt, or dug into land, or carried away to sea.

6. The entire processes of precipitation and dealing with the sludge can be, and must be, effected without substantial nuisance to the neighbourhoods where they are carried on.

7. The liquid portion of the sewage, remaining after the precipitation of the solids, may, *as a preliminary and temporary measure*, be suffered to escape into the river.

8. Its discharge should be rigorously limited to the period between high water and half ebb of each tide, and the top of the discharging orifice should be not less than 6 feet below low water of the lowest equinoctial spring tides.

9. By these means much of the existing evil will be abated.

10. But we believe that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a *permanent* measure. It would require further

purification ; and this, according to the present state of knowledge, can only be done effectually by its application to land.

11. In the case of the Metropolis the best method of applying the liquid to land with a view to its purification would be by intermittent filtration. We have reason to believe that sufficient land of a quality suitable for this purpose exists within a convenient distance of the northern outfall. The liquid portion of the sewage would be pumped up to this land from the separating works, and after filtration would be conducted to the river.

12. We do not know whether suitable land in sufficient quantity can be found in convenient positions near the southern outfall. If not, the liquid must be conveyed across to the north side by a conduit under the river.

13. If suitable land in sufficient quantity and at reasonable cost cannot be procured near the present outfalls, we recommend that the sewer liquid, after separation from the solids, be carried down to a lower point of the river, at least as low as Hole Haven, where it may be discharged. In this case it will also be advisable that the liquid from the southern sewage should be taken across the river, and the whole conveyed down the northern side. It may be found that the separating process can be effected more conveniently at the new than at the present outfalls ; this will depend on various considerations of cost and otherwise.

14. If the outfalls are removed farther down the river the main conduit or conduits may, if thought desirable, be made of sufficient capacity to include a general extension of the drainage to the whole of the districts round London, as recommended by Sir Joseph Bazalgette and Mr. Baldwin Latham. In new drainage works the sewage should be, as far as possible, separated from the rainfall.

PRECIPITATION PROCESSES.

Dr. Tidy on the treatment of sewage.

While these pages are in the press, Dr. Meymott Tidy's paper on "The Treatment of Sewage," read before the Society of Arts, 14th April 1886, has been published in the Journal of that Society, 8th October 1886.

With regard to the treatment of sewage on land by irrigation or by intermittent downward filtration, no new facts are brought forward in this paper and no arguments advanced, either for or against these processes, which have not been thoroughly discussed in the preceding pages. But as the author is an acknowledged authority on the treatment of sewage by chemical precipitation, we have thought it desirable to quote his opinions on this point. He says :—

My own experience leads me to speak very highly indeed of the combined use of lime and sulphate of alumina. The quantity of lime which is to be added first should be such as to render the sewage faintly alkaline. Probably at the rate of from 5 to 7 grains per gallon will be needed for this purpose. It should be added as milk of lime, and should be thoroughly stirred in by means of a paddle-wheel, or other efficient mixer. A flow of a few yards should now be allowed, to permit the aggregation of the precipitate. This having taken place, a solution of crude sulphate of alumina, in the proportion of about 5 grains of sulphate of alumina, is to be added, and the sewage again actively stirred. In the alkaline condition of the sewage the alumina will be precipitated, and will then combine with a portion of the organic matter, forming together an insoluble precipitate. Thus treated, the sewage should be allowed to flow into tanks for the precipitated matters to collect.

Lime and sulphate of alumina.

Dr. Tidy admits the value of iron compounds as precipitants, but hesitates to recommend their use owing to the blackening of the mud banks, which results from the formation of sulphide of iron. "As regards the use of phosphates as precipitants, the effluent is almost certain to contain some phosphoric acid," which greatly aids the growth of low forms of fungoid life.

Iron compounds.

Phosphates.

If a "high degree of purity" in the effluent water is desired, Dr. Tidy considers it advisable to allow the effluent, after leaving the precipitation tanks, to flow over and through a small area of land (loamy sand or gravel), an acre to every 5000 or 7000 people being sufficient.

Filtration through land.

The details of treatment essential for the success of a precipitation process, Dr. Tidy considers to be :—

Conditions for successful precipitation.

1. That the sewage treated be fresh—not more than twenty-four hours, and certainly not more than forty-eight hours, old.

2. That the larger solid matters be strained off before treatment.

3. That sufficient chemicals be employed to effect complete precipitation, disinfection, and deodorisation of the sewage.

4. That after the chemicals are added, the mixture be well stirred.

5. That there should be sufficient tank accommodation. "The treated sewage should flow through at least two subsiding tanks in series, the first being capable of holding one hour's flow, and the second not less than four hours' flow. The tanks should be at least 4 feet deep, and the overflow of the defæcated sewage should be over a

weir, not more than half an inch below the surface. There should be a double set of tanks for successful working. Sufficiency of tank accommodation is also important, so that the sludge may be frequently removed, otherwise the freshly precipitated sewage may be contaminated by the decomposing materials of a previous precipitation, or a nuisance result from a collection of decomposing matter. Many a good effluent is spoilt by foul materials being allowed to collect in the subsiding tanks. These materials undergo putrefaction, the gases given off contaminating the effluent. The solid matters, becoming specifically lighter than the liquid by the gases of putrefaction developed in and amongst them, rise to the surface, the floating black masses presenting an objectionable appearance, and discharging offensive products into the air. After a time these black masses sink, and thus by constant commotion of the precipitated matters, a turbid effluent, with a more or less foul smell, results."

6. That the defæcated water should flow through a shallow open conduit, not less than a quarter of a mile in length, before being discharged into the stream.

7. That the stream into which the effluent is discharged should have a free run, and in volume be not less than eight times the volume of the defæcated sewage.

8. That the tanks themselves should not only be emptied of the sludge, but thoroughly cleansed before being refilled.

Dr. Tidy's admission.

It is important to note that Dr. Tidy admits that precipitation processes are not adequate to produce an effluent of "a high degree of purity," and that it would therefore be necessary where such an effluent is required to purify it by filtration through land.

Mr. Dibdin's paper on Sewage-sludge.

In a paper on "Sewage-sludge and its Disposal" by Mr. J. W. Dibdin, read before the Institution of Civil Engineers, 25th January 1887, it is stated that some of the suspended matters of sewage are soluble in solutions of lime. Mr. Dibdin says, "the use of an excessive quantity of lime, while affording a rapid settlement of the sludge, and a more or less clear effluent, dissolves a by no means inconsiderable quantity of the offensive matters previously in suspension, and this is apt to render the last state of the liquid worse than its first."

Lime in excess.

Sulphate of iron superior to sulphate of alumina.

Mr. Dibdin considers protosulphate of iron superior to sulphate of alumina for sewage treatment by precipitation. He found that in twenty-three samples of Metropolitan sewage treated by 3·7 grains of lime in solution and 2·5 grains of sulphate of iron per gallon, an average reduction of 18 per cent of dissolved oxidisable organic matter was effected. The annual cost of the chemicals required to treat by this process the whole volume of Metropolitan sewage (156,800,000 gallons daily) is estimated at £31,755—lime costing £1, sulphate of iron £2 per ton. By treatment with 5 grains of lime in solution and 5 grains of sulphate of alumina per gallon, the same average percentage reduction of dissolved oxidisable organic matter was effected, but the annual cost of this treatment is estimated at £82,125—sulphate of alumina costing £3 : 10s. per ton. Five grains of lime in solution and 5 grains of sulphate of iron to the gallon are no more efficacious in removing dissolved organic matter than 3·7 grains of lime and 2·5 grains of sulphate of iron to the gallon. By the addition of 5 grains of animal charcoal per gallon to the 5 grains of lime and 5 grains of sulphate of iron, a further reduction of 4 per cent of dissolved oxidisable organic matter is effected, but at an additional yearly cost, estimated at £182,500. Even where such large quantities as 56 grains of lime, 12 grains of sulphate of iron, and 40 grains of sulphate of alumina per gallon were used, the average reduction of dissolved oxidisable organic matter was only 31 per cent. The additional 13 per cent reduction over that effected by 3·7 grains of lime and 2·5 grains of sulphate of iron per gallon is estimated to cost yearly the enormous sum of £771,245. It is thus seen that no benefit corresponding to the enormously increased cost is derived from the use of an excessive quantity of chemicals in precipitating sewage.

Cost of animal charcoal.

No benefit from use of chemicals in excess.

Mr. Dibdin conducted a series of precipitation experiments on solutions of clear mutton extract of different strengths. When a solution containing 10 per cent of the clear mutton extract was treated with 3·7 grains of lime and 1 grain of sulphate of iron per gallon, 87·2 per cent of oxidisable organic matter was removed from solution. But in a solution containing 0·1 per cent of the mutton extract only 56·0 per cent of the oxidisable organic matter was removed by the above treatment. These experiments appear

Precipitation in organic solutions of varying strengths.

to indicate that the stronger the sewage in dissolved organic matters the larger will be their proportional reduction by the use of chemical precipitants, and thus an explanation is afforded of the varying results obtained by treatment with the same process of samples of sewage which were of different strengths and characters.

Composition of pressed sludge.

The average composition of pressed sludge from the Metropolitan sewage Mr. Dibdin states to be: moisture 58·06 per cent, organic matter 16·69 per cent, mineral matter 25·25 per cent, nitrogen 0·87 per cent (=ammonia 1·06 per cent), phosphoric acid 0·658 per cent (=phosphate of lime 1·44 per cent).

Professor Robinson's formula.

Professor Robinson's formula for calculating the weight of pressed sewage-sludge formed from a given quantity of the moist precipitated matters in the tanks may be found useful.

Let W = the weight of the moist sludge,
„ P = the percentage of moisture remaining in the pressed sludge,
„ X = weight of sludge when pressed,

$$\text{Then } X = \frac{10W}{100 - P}.$$

"A B C" process at Aylesbury.

On a visit to the Native Guano Company's works ("A B C" process) at Aylesbury on 8th January 1887, we found that a considerable portion of the sewage, which was much diluted with storm-water, was escaping untreated into the stream by the storm-overflows. There was no offensive smell due to the treatment of the sewage or to the process of manufacturing the manure. As to the quality of the effluent, we learn from analyses made by Dr. Tidy and Professor Dewar of samples of sewage and effluent taken half-hourly for twenty-four hours during three days in 1885, that the matters in suspension in the sewage are almost completely removed, and that the amounts of ammoniacal nitrogen and chlorine in the sewage and effluent are practically the same. As regards the amounts of organic matter in solution in the sewage and effluent we find from the first series of analysis (January 29-30) that the organic

Analyses of sewage and effluent.

matter in solution in the sewage was, on the average for twenty-four hours, 18·246 grains per gallon, whilst that in the effluent amounted to 18·46 grains per gallon—a very slight increase. In the second series (March 2-3), and in the third series (March 16-17), the tables of organic matter in solution given in the first series are not continued, but the *oxidisable* organic matter in solution in the effluent is (average of twenty-four hours) only 38 per cent of that in the sewage in No. 2 series, and is 53 per cent in No. 3 series, as measured by the amount of oxygen absorbed from potassium permanganate by the filtered sewage and effluent respectively. Although in these analyses the samples of sewage and effluent were taken half-hourly, and the error thereby avoided of comparing a sample of strong day sewage with the effluent from a weak night sewage—an error which caused an eminent expert in his evidence before a judicial committee of the Privy Council to assert that $2\frac{3}{10}$ grains of ammonia in the raw sewage were reduced to $\frac{6}{10}$ grain in the effluent, and that the difference must have been absorbed by the charcoal, whilst nearly 10 grains of chlorine in the raw sewage were reduced to 7 grains in the effluent, the missing 3 grains being probably absorbed by the clay—yet the samples were not truly average samples, for *they were not mixed in the proportion indicated by gauging at the time each sample was taken*—the method devised by the British Association Sewage Committee (see p. 179)—but four half-hourly samples were mixed *in equal proportions* to form a sample for analysis. A source of error has therefore not been eliminated which considerably invalidates the results of these analyses. It is also needful to bear in mind that the oxidisable organic matters form an unknown proportion of the total organic matters in any sample, and that we know nothing as to the deleterious properties of the oxidisable as compared with the non-oxidisable organic matters.

Samples taken half-hourly.

Samples analysed not truly average samples.

The matters precipitated from the sewage (the sludge) are passed through a filter-press, and issue as compressed cakes containing 50 to 60 per cent of moisture. These cakes, after admixture with some sulphate of magnesia, are

Drying of the sludge.

passed through a drying cylinder—a granular manure being produced, containing about 30 per cent of moisture. This manure is said to lose by air-drying more moisture, and is usually sold with from 14 to 18 per cent of moisture in it. In this condition it is stated to contain from 3 to 4 per cent of ammonia, and about 5 per cent of phosphoric acid, reckoned as tricalcic phosphate of lime, and sells for £3 : 10s. per ton. Estimating the ammonia at 7d. per lb. and the phosphoric acid at 4d. per lb., the theoretical value of this manure would be about £4 per ton. We admit, with the Royal Commission on Metropolitan Sewage Discharge, that we completely fail to understand how mere dried sewage-sludge can contain so large a percentage of ammonia, and have so high a value.

Value of the manure.

At Tottenham Hillé's process, and at Leyton the Coventry process, have been recently discontinued—the sewage of both places being now treated by lime and black-ash waste (Hanson's process). The black-ash waste, in its crude state the refuse of alkali works, is prepared by Mr. Hanson and sold by him in London in a granular condition, suitable for mixing with sewage, at £3 : 10s. per ton. It is stated by Mr. W. C. Young, consulting chemist to the Lee Conservancy Board, to contain 9 per cent of hyposulphite and 23 per cent of sulphite of lime, which, owing to their being powerful reducing or deoxidising agents, impart to the waste considerable antiseptic and deodorising properties. They are not present in new black-ash waste, but are formed in the heaps of this material which have been long exposed to the air, by the oxidation of sulphide of calcium. The hyposulphite of lime being soluble in water, some of it passes off in the effluent. The beneficial effect of the introduction of the hyposulphite with the sewage effluent into the river Lee has been very marked. During 1885 the Lee was in a most filthy condition—chiefly due to the discharge into it of the effluent from the Tottenham sewage—and gave rise to a great popular outcry. In 1886, after the black-ash waste process had replaced Hillé's, the river was found to have very much improved, and this improvement is

Lime and black-ash waste.

Its antiseptic properties.

Improvement in the Lee.

attributed by Major Flower, engineer to the Lee Conservancy, to the action of the black-ash waste, both on the effluent flowing into the river and on the foul matters previously deposited in its bed.

On a visit we paid with Major Flower to the sewage works at Tottenham and at Leyton on 12th January 1887, we found the process working satisfactorily at both places. At Leyton, lime (16 grains to the gallon) and black-ash waste (4 grains to the gallon) are well mixed with the sewage before it enters the depositing tanks. The cost of this treatment is at the rate of 9d. per head of the population per annum, and is stated to be only two-thirds of the lime and sulphate of alumina treatment formerly practised, whilst the effluent is better. The wet sludge is passed through filter-presses; there being no demand for the resulting cake, a small premium is paid for its removal. The storm-waters from the outfall sewer pass along ditches in osier-beds before escaping into the river Lee. At Tottenham a rather larger quantity of black-ash waste is used. We took a sample of the effluent from the tanks, and found it to contain 20 parts per million of free ammonia and 8·6 parts per million of albuminoid ammonia. Although this effluent is similar in composition to a weak, crude sewage, and has been kept in an open bottle for over a month, no putrefactive changes have taken place in it. Its sediment has contained, during the whole of the period, numbers of infusoria, which are as abundant and active now as on the first day the sample was taken. It thus appears that although black-ash waste may prevent the formation of putrefactive organisms (Bacteria) when used in sufficient quantity, it does not interfere with the growth of those microscopic organisms which, by feeding on organic matters, are capable of purifying foul waters, without the production of foul gases from putrefaction.

The process at Leyton.

The effluent at Tottenham.

Its freedom from putrefactive changes.

An experimental trial has been made at Tottenham of Spencer's magnetic carbide of iron as a filtering material for the effluent. We found that the effluent, of the strength noted above, when passed slowly through a filter consisting

Magnetic carbide of iron as a filtering material.

of 12 inches of sand upon 18 inches of the magnetic carbide, was very considerably purified. The ammonia and albuminoid ammonia were markedly reduced, whilst the nitrates were increased from the merest trace in the effluent to a considerable amount in the filtrate. These analyses indicate that a powerful oxidising action takes place in the filter. The magnetic carbide of iron never requires to be renewed, but aëration is necessary. We are informed that the filter beds of this material at Wakefield, used to filter the foul water of the river for domestic supply, have never been renewed since they were first constructed about seventeen years ago. The longer the water or sewage remains in contact with the filtering material, the greater is the purifying effect produced.

Purifying effect.

RECENT FOREIGN OPINIONS ON SEWAGE TREATMENT.

Report of Turin Commission.

The Report of a Commission appointed by the Municipal Authority of the city of Turin to inquire into the methods adopted for the disposal of the refuse of towns in various parts of Europe has just been issued. From it we find that the Commission arrived at the following conclusions with regard to the disposal of sewage:—

Failure of precipitation.

1. The chemical or precipitation methods for the treatment of sewage, which have been tried up to the present time, do not succeed in separating the manurial ingredients, are costly, clarify, but do not purify the water, which, moreover, remains liable to undergo putrefaction afresh if the process is not followed by some method of oxidation.

Irrigation the only method.

2. The only method recognised up to the present time as really efficacious for the purification of sewage is irrigation, carried out in a proper way upon suitable soil; after the separation of the suspended matters this method is deprived of danger and of inconvenience, and in our districts would give the best agricultural results.

Mr. A. Aird of Berlin has kindly forwarded to us an account of the proceedings of the Bundestag (a Governmental Board on which representatives of all the German States discuss important measures), from which we find that it was proposed, at a meeting of that body in April 1886, that "irrigation farms for the utilisation of town sewage should be placed on the list of institutions requiring special permission for their establishment. . . . *The Bundestag declined to entertain the proposition.*" "This means," says Mr. Aird, "that the ruling authorities in Germany know that sewage irrigation can be carried out without causing any nuisance; that purification of sewage by sewage irrigation is of immense importance to public health and to the state of the rivers, and therefore they declare it permissible anywhere."

Decision of the German Bundestag.

SUMMARY

Having reviewed the most important methods that have been practised for the removal of refuse matters from towns, we have been led to adopt the following definite principle: that the method which does, in practice, where it is anything like efficiently carried out, remove at once and completely from the vicinity of habitations the various sorts of refuse in the most expeditious manner, is the one which must be the most conducive to health.

Principle arrived at.

We have pointed out that the principle of all dry methods of excremental removal, without exception, is to leave the excremental matters in and about the house for a certain time—so long, in fact, as they do not become an absolute nuisance. We maintain that this is essentially wrong in principle, and we point in support of our opinion to the facts with regard to the state of the health of the inhabitants of midden-closet towns. Many instances more than those we have quoted are daily coming under our notice. As to the dry earth system, its principle is the same, though its action is more thorough. Although it has been shown to have a great advantage where it has replaced midden-heaps and cesspools, we maintain, with the late Drs. Rolleston and Parkes, that it has not been shown that the compost is disinfected as well as deodorised. And until this is proved to be the case

Dry methods *all* violate it.

Deodorisation and disinfection not the same thing.

it is safer to resort even to the offensive pail system, where excrement cannot be allowed to remain within dwellings for any length of time on account of the great nuisance that would be caused by it, than to a plan which destroys the warning but is not proved to have removed at the same time the danger. It has at various times been proposed to deodorise coal gas: the result of this would certainly be that accidents by poisoning and by explosion would be increased to an enormous extent. We know that the poisonous ingredient *par excellence* of coal gas—the carbonic oxide —is perfectly inodorous; we know also that the emanations which produce typhoid fever are not offensive or disagreeable to the smell; and it is a *presumption,* as Dr. Parkes said, to suppose that all danger of their production is removed by mixing the excrement with earth. But even were this presumption to become a demonstrated fact, the greatest objection to the earth system (one which is essential to it because it is a dry system) would still be as strong as ever, viz. that whenever the earth supplied happened to be in too small quantity, too moist, or of bad quality, or the air to be very damp, or the compost wetted through carelessness or otherwise, the danger of infection would at once arise. How frequently one or more of these conditions would be fulfilled need hardly be pointed out.

Comparison with coal gas.

Miss Nightingale well says, in her remarks on the *Progress Reports* in the Indian Sanitary Report (1870), p. 45: "The true key to sanitary progress in cities is, water supply and sewerage. No city can be purified sufficiently by mere hand-labour in fetching and carrying."

"As civilisation has advanced, people have always enlisted natural forces or machinery to supplant hand-labour, as being much less costly and greatly more efficient."

We turn, then, to review briefly the results already attained by the water-carriage system, despite all the disadvantages of it (when badly carried out) which have been put forward in these pages. We know what it has done; we know that in the towns where it has been introduced in conjunction with other sanitary improvements, it has been the means of practically annihilating cholera; we know that it has been very little less effectual in the extermination of typhoid fever. We are sure that it is the speedy removal of the refuse matters that has accomplished this, because, in towns where free exit has not been allowed for the sewage from the sewers, the death-rate of typhoid fever has only very slightly diminished, or has slightly increased, or even (in one case) has very considerably increased. Such cases, although deplorable in themselves, are instructive to the sanitarian in pointing out beyond the question of a doubt that it is especially the improved sewerage arrangements that have effected these results. We have seen, too, that by the construction of deep drain-sewers the mortality from phthisis has been diminished to a very remarkable extent, amounting in one case to nearly half the former number of deaths.

Results attained by water-carriage system.

And although we have, for a multiplicity of reasons, felt ourselves justified in condemning the drain-sewer system, we have certainly to thank it for the discovery of the all-important fact that one of the most potent causes of phthisis is a water-logged subsoil; so that while we advocate impervious pipe sewers, we must also insist that towns shall be provided with deep subsoil drains.

What the drain sewers have shown.

Not only this, but we have also seen that these special improvements have been accompanied by the still more important one of a reduction in the general death-rate, amounting to about a fifth part of the previous number of deaths in nine out of the twenty-five towns reported on by Dr. Buchanan.

Sewage; how got rid of.

Having then, the sewage to deal with, the first object must be to get rid of it in an unobjectionable manner, and the next to utilise it if possible.

Plenty of evidence has been given to show that it must not be sent into the rivers, as has heretofore been almost invariably done; and that it is only a little less objectionable to resort to this plan after a preliminary straining off of the suspended matters.

Filtration.

We have, however, seen that by intermittent downward filtration through soil, sewage can be adequately purified, so that the effluent water may be turned into a stream: by this plan, however, the manure which is so much wanted is almost entirely lost, the greater part of it escaping in solution in the effluent water in the form of nitrates and nitrites.

Precipitation processes.

As to the utilisation of sewage, we have shown the futility of all attempts at precipitation of its valuable constituents; in fact, "it is hopeless," as Dr. Hewlett says, "by either one or any of these operations to render the effluent water anything else than sewage."

Irrigation.

Finally, with regard to irrigation farming, the facts that we have brought together seem to us to show clearly that it satisfies the three conditions which we laid down (p. 366)—the sewage is purified, a profitable agricultural return is ensured, and the health of the neighbourhood is not endangered.

Conclusion.

We are, then, reduced to the following simple issue:

wherever it is possible, irrigation should be carried out, the sewage having been previously freed, by one or other of the methods described, from the offensive suspended matters, which must be deodorised to prevent the production of a serious nuisance. Wherever, on the other hand, irrigation is practically impossible, intermittent downward filtration through soil affords the means of satisfactorily purifying the sewage.

We have collected the facts, arranged them, and weighed the evidence afforded by them; it is for the future to decide how far our conclusions have been warranted.

The preceding summary was written in 1870, and now, after the lapse of seventeen years, we see no reason to alter it.

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THE END

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