CHAPTER V.

RIVERS.

SINCE one of the most elementary necessities of life is water, the proximity of a water supply is always a determining factor in the choice of a locality for human habitation. Great regions in the Asian, African, and American continents, and the vast extent of Central Australia, owe their deserted character primarily to their dryness. Large cities have usually been established somewhat inland from the mouths of rivers, in order to be in reach of abundant fresh water. Where for protection, or for mining reasons, habitations have been constructed in high places, they have either been in the neighbourhood of a mountain lake, like the city of Quito, or have depended on wells sunk in the rock.

As the area of cultivation extended, migration proceeded up the smaller rivers and streams, outlying districts being supplied by shallow wells sunk in the surface gravel of former river-beds, or in favoured cases by springs. The only contamination to be ordinarily met with in drinking water then arose from suspended mineral matters or from decaying vegetable debris. The former were dealt with by simple subsidence or by crude sand filtration; the latter is still a difficulty in forest regions, especially in the tropics, where dysentery

and fevers attend the use of marshy waters. Malaria, which signifies simply "bad air," owes its ill effects in probably a greater degree to bad water, as travellers who have boiled or properly filtered their drinking water have generally escaped the infection.

At a very early period, lakes and pools and rivers were subject to contamination by the visits of animals, many of whose parasitic diseases are known to be communicable to man (p. 48). But as the population in certain districts grew denser the quantity of water used and fouled became progressively greater. At first only the water used for domestic purposes, cooking, and ablution found its way into the streams, the excreta being disposed of in dry earth in the primitive manner still common in the East; but as the population augmented the contamination of the soil increased. At first the greater part of the polluting matter was consumed and rendered harmless by vegetation, just as a properly managed sewage farm will deal with the excreta of a district; but with the aggregation into villages and towns the upper layers of soil became saturated with excrementitious matters, which passed without appreciable purification into the water of surface wells. The neighbouring streams were polluted by drainage, and in their course joined with the other affluents in carrying the diluted sewage of the towns and villages into the rivers and thence to the sea. A considerable amount of purification took place in transit by deposition, oxidation, and aquatic life; but this became less and less effectual as the proportion of discharge increased. A further element of impurity was added by the advent of manufactures, the effluents from dye-works, breweries, and other industries being discharged into the streams. By these combined causes the water of most rivers and streams in populated districts was rendered unfit for consumption, and new sources of supply had to be sought for at a greater distance. Thus in 1894 the Seine was so polluted near Clichy that Dr. Billings observed, "Bubbles of gas from the putrefying slime at the bottom escaped from the dark surface, and no fish could live in it."

Dr. Bruce Lowe's recent report to the Local Government Board on the examination of the Dee above and below Chester shows that he and Dr. Ballard found that "the raw sewage of several large towns was poured directly into the Dee, and that pollution of the stream below the weirs could be carried by the tidal wave into close proximity to the Chester waterworks intake. The water was so polluted as to destroy the fish that came up the river." They concluded that "a stream receiving such contaminations could not be regarded as a safe source of public water supply, even if before it was delivered to the public it was subjected to the best process of sand filtration."

It will be within the memory of many Londoners how black and offensive the Thames was formerly between the bridges. Since 1859 the Main Drainage

scheme and the embankment of the Thames have immensely improved the condition of the river, so that fish that could not formerly live in the foul water have now been noticed as high as Westminster Bridge. At that time, as Dr. E. Frankland reported, "the silvery Thames was for several weeks converted into a black, seething, and stinking canal, its sluggish waters being carried backwards and forwards by the tide through London and Westminster, and the stench in the committee-rooms of the Houses of Parliament became so unbearable as to render necessary the filtration of the outer air through cloths wetted with chloride of lime."

An instance of how such injury to watercourses is still permitted to continue occurs in a report to the Halifax Council as to the district of Upper Greetland, Yorkshire, in April, 1896. The local stream is stated to be "as badly polluted as ever, and although it had been condemned by three medical officers, it was still allowed to be used for cattle, and even by human beings. The milk from the cows which drank from the stream was sold in the Halifax district." The connection between polluted milk and disease has been so frequently demonstrated that it is obvious cattle should not have access to such water. It also appeared that pigs were in the habit of wading in the stream, and this animal is particularly subject to parasites.

A striking example of the pollution of a river by the domestic and manufacturing sewage of a town is given in the Report of the Massachusetts Board of Health, 1890 (p. 472). Above the town of Fitchburg, of 22,000 inhabitants, the water of the Nashua river has the following composition: free ammonia, ·0004 parts per 100,000; chlorine, 0·39; nitrogen as nitrites, ·0001. Below the town the respective figures are ·0326, 0·83, and ·0014. Thus the ammonia has enormously increased, the chlorine has more than doubled, and the nitrite is fourteen times as much, three ingredients which are characteristic of sewage pollution. A series of interesting chemical maps, illustrating with exceptional clearness other features of the kind, is included in the volume. This method of plotting certain of the analytical results on sketch maps of the river-basins furnishes an exceedingly useful bird's-eye view of the effect of tributaries and local discharges on the main stream, which would be still further elucidated if the maps were tinted to indicate the geological formations.

A series of such maps drawn on a larger scale, for which the name "hydrochemical" might be proposed, would be an important contribution to the study of our water supplies, and should be undertaken by some of our public authorities. It does not seem creditable to England that, while a state like Massachusetts should institute inquiries with such care and in such detail that their results are of benefit to the whole world, our local bodies should often be battling helplessly with problems in such a crudely experimental way as to cost large sums to the ratepayers for

abortive schemes which a little more knowledge would have prevented from being undertaken.

In 1865 a Royal Commission was issued for inquiring how far the present abuse of rivers in England for the purpose of carrying off the drainage of towns and the refuse of manufactures might be remedied, and how far such products could be utilised or rendered harmless before reaching the rivers. The reference included also an extensive inquiry into the water supplies then existing. The results were recorded in the series of reports of the Rivers Pollution Commissioners ending in 1874. Their researches were very valuable, but their suggestions as to the limits of impurity in discharges which should be permitted to pass into watercourses were ultimately abandoned or postponed by Government. A great improvement was effected when the intakes of the London companies were transferred to points higher up the stream, as, for instance, that of the Southwark and Vauxhall Company, from Battersea to Sunbury, near Hampton Court. But it must be remembered that these intakes still include the local sewage from the upper portions of the river.* The filtration to which the water is afterwards subjected is considered in Chapter IX.

* To show how important is the position of the intake, the following may be cited from the Report of the Medical Officer to the Local Government Board, 1894 (p. 18): "In the cholera epidemic at Paris in 1872, the inhabitants of those communes drawing their supply from below the main outfall sewer died of that disease at a rate nearly fourteen times as great as those who were supplied from the same river at a point above Paris."

The pollution of streams is prohibited under penalties by the Public Health Act of 1875, the Rivers Pollution Prevention Act of 1876, the Local Government Act of 1888, and by local Acts, such as the Public Health (London) Act of 1891, and by bye-laws of sanitary authorities. Many of these Acts, however, are largely inoperative owing to the numerous excepting clauses, but in any case the discharge of solid or liquid sewage, or indeed of any solid matter, into streams, is illegal. It is, therefore, the duty of an inspector of nuisances to guard against the common practice in towns and villages of allowing the washings of stables and pigsties to flow into any watercourse, and he should insist on the removal of all closets on the banks of running streams and prevent the discharge into them of all house refuse, &c.

Since the operation of these Acts it has been found possible and even remunerative for manufacturers to utilise waste products by precipitating, filtering, evaporating, distilling, and burning, so that chemicals are recovered, organic matters used as fuel or manure, and clean effluents only allowed to be discharged.

On August 21st, 1896, Mr. Justice Gye made an order, with full costs, requiring the Corporation of Andover to abstain from polluting the river Anton with sewage. He found that the Council had not used any means of rendering harmless the sewage so calling into the stream. This was one of the rare fases where private persons had taken action under

the Act, the plaintiffs being riparian and mill owners.

The Local Government Board has of late declined to sanction schemes for the drainage and sewage disposal of districts unless the manufacturers submitted their effluents to a preliminary treatment before passing them into the sewers.

The standards of the Thames Conservancy for districts below the intakes of the London Water Companies are that any discharge into the river should be—

1. Free from offensive odour.
2. Free from suspended matter—*i.e.*, perfectly clear.
3. Neither acid nor alkaline to test-papers. (This is impossible: natural waters are almost invariably acid to one test, on account of free carbonic acid, and alkaline to another, owing to carbonates. Hence "acids and alkalies not naturally present" should be specified as prohibited, or limits of permissibility stated.)
4. Not more than sixty grains per gallon of total solids.
5. Not more than two grains per gallon of organic carbon and 0·75 grains of organic and ammoniacal nitrogen.
6. Not less than one cubic inch of free oxygen per gallon.

Such a water undiluted would usually be still not potable.

The German Government Act of 1894 prohibits the discharge into rivers of (*a*) substances of such a nature that their introduction may give rise to an infectious disease, (*b*) or in such quantities as may involve an injurious pollution of the water or of the air or a distinct annoyance to the public. A special officer of the province is to determine as to the things and quantities covered by this Act.

During their rapid upper course, mountain streams are generally turbid. The suspended matters are gradually deposited as the current slackens; but, owing to fresh accession from tributaries, river water is rarely bright, and is sometimes very difficult to clarify by filtration. An example of the change of a river in its flow is furnished by the Schuylkill, which rises in the anthracite region of Pennsylvania, receiving much refuse mine water and becoming so impregnated with iron salts and free mineral acids as to be quite unsuited for drinking or manufactures. In the course of 100 miles it passes over an extensive limestone district, and receives several large streams highly charged with carbonate of lime. In this way the acid is neutralised, and the iron and most of the lime are precipitated, with the result that the river becomes purer; and at its junction with the Delaware at Philadelphia it contains neither free sulphuric nor hydrochloric acid and only small traces of sulphate of lime, and is, in fact, a soft water.

Rivers which are hard at their source generally undergo some softening during their flow, while the total solids increase from the influx of salts from the land.

Thus Thames Head water near Cirencester contains 27·44 parts per 100,000 of solids; hardness, 23. As supplied to London it contains 30·94 solids and 17·3 hardness.

As to the natural organic purification of rivers, very opposite statements have been made. The late Dr. Tidy contended that water containing 20 per cent. sewage became purified by natural oxidation in a flow of ten or twelve miles; whereas Dr. E. Frankland, by a series of experiments on the Irwell and on the Thames, sought to establish that 200 miles would not be sufficient for the purpose. But at that time the *rôle* of bacteria was not properly understood. Atmospheric oxygen alone will not readily attack organic matter in the absence of microbes; it is the number and nature of the latter that determine the rate and completeness of natural purification. In this process the organic matters containing carbon and nitrogen are partly absorbed by microbes as food and converted into their cell-walls and protoplasm, and in part are changed into compounds of volatile vegetable acids, such as butyric, which communicate unpleasant odours and taste. Other products are the ptomaïnes, some of which are powerful poisons; these remain in the water after filtration.

On the continent, the Isar, Spree, Limmat, and Danube have recently been examined by bacteriological methods, and the purification effected determined during the flow under different conditions.

But the most important agents in the natural improvement of waters are the "nitrifying organisms," very minute micrococci of at least two species, which have been isolated and described by Winogradsky, Warington, and P. F. Frankland. One kind effects the conversion of ammonia into nitrites, and the other of nitrites into nitrates. In the process of nitrification, which has long been known in connection with the manufacture of saltpetre, nitrogenous organic fluids, like urine and the runnings from manure, when mixed with alkalies or lime and exposed to air, have their organic carbon converted into carbonates, and the nitrogen into ammonia, to be, in its turn, changed into nitrites and finally into nitrates, in which simpler form the whole becomes "mineralised" and is no longer injurious. The organisms which effect these changes are present in almost all soils and waters, but their activity is dependent on certain conditions:—

1. The solution must be neutral or alkaline; hence heavy and sour soils will not nitrify. Acid discharges from factories also entirely put a stop to the natural process of purification.

2. The presence of air seems necessary. Nitrification does not occur more than a few feet deep in soils (Warington), and then only when such soils are porous, like sand or gravel.

3. The action is more vigorous in the absence of light, so that in waters exposed to full sunlight it is suspended, and the organisms may actually be killed.

In waters loaded with organic matter and containing little dissolved oxygen, *denitrifying* organisms reduce the nitrates to nitrites, and may eventually convert them into nitrous and nitric oxide, or even into nitrogen gas. These gases dissolve in and finally escape from the water, and thus probably account for the fact that the amount of nitrogen in the nitrates and ammonia produced is always lower than the nitrogen in the original organic matter. In comparing a sample of water taken from a stream at a point where it is much polluted with one taken further down, there is often a very marked improvement at the lower point, owing to the dilution caused by purer tributaries and by water filtering into the stream from underground sources. If a river is flowing very smoothly, different sources do not mix; the water of a turbid or coloured affluent can often be traced as a separate streak along a river for a great distance.

In regard to the self-purification of rivers, Dr. P. Frankland ("Bacterial Purification of Water," *Proc. I.C.E.*, November, 1896), instances his examination of the river Dee for forty miles of its course. Above Braemar the Dee was found to yield only eighty-eight microbes per cubic centimetre; after receiving the sewage at Braemar, however, the number went up to 2,829 per cubic centimetre, whilst some miles further down the number had fallen to 1,139; below another point, where some more sewage had gained access, the number rose to 3,780, while some miles further it again fell to 938; with fresh access of sewage it rose to 1,860, lower down again falling to 950 microbes per cubic centimetre, "a most striking example of repeated pollution and purification within a limited distance." Dr. Frankland states that the chemical examination was not sufficiently delicate to reveal these changes.

By waterfalls and weirs the water is thoroughly mixed and also aerated. The improvement effected thereby is not so considerable as was formerly supposed. Dr. Leeds in 1890 examined the water above and below Niagara falls, and showed that the aeration did not cause any decrease of the free ammonia or in the oxygen consumed, and gave only a small reduction in the albuminoid (*Journal of Amer. Chem. Soc.*, November, 1890). Dr. P. Frankland (Third Report to Royal Society, 1894, p. 516) found that moderate agitation, with intervals of rest, on the whole promotes the growth of bacteria. In low-lying districts the construction of weirs and dams for mills, &c., frequently causes great injury to the health of the locality by rendering the soil damp and water-logged above the obstruction. In such a case the watercourse should be securely embanked, and the drainage carried to the lower part of the river, as it is to a great extent in London. According to section 33 of the Sanitary Laws Amendment Act of 1874, "any sanitary authority may, subject to the provisions of this Act and of the Sanitary Acts, buy up any water-mill, dam, or weir which interferes with the proper drainage of or the supply of water to its district." A free growth of algæ and larger water plants uses up a large part of the ammonia and nitrates in a water; but, on the other hand, they always render the water offensive to the smell and taste, and corrupt it by the products of their decay.

It is of the highest importance that the current of a river should be kept strong enough to carry along the solid matters contained in it, otherwise they deposit in foul banks along the shore. These at low water are converted by the heat of the sun into fœtid breeding grounds of germs, and the shallow water is a concentrated solution of highly deleterious matter. And it is probably due to this fact that it is generally in the time of, or just after, periods of drought and warmth that epidemics arise. "Compensation" reservoirs, to divert floods and store the water so that the river becomes less overcharged, are also made necessary by the fact that the water, in addition to being turbid, is always greatly increased in foulness, as, besides the washings of manured land and of streets in towns, numberless abominations, which get into the smaller tributaries and are left there to putrefy, are washed out by floods into the main stream. Thus in some cases small villages have produced epidemics in riparian towns situate below on the same river. Intermittent stagnancy, succeeded by flood, is favourable to the growth and dissemination of the more dangerous organisms. The storm-water collected in a reservoir would have time to deposit, and would be a reserve against periods of drought such as recently visited, with such serious results, the town of Leicester. By reservoirs the "scouring action" of the stream can be kept continuous, and the stored water used to supplement a slackened flow in times of drought.

Dr. Shirley Murphy has shown that in 1894 sporadic cases of enteric fever occurred in London after the delivery of inefficiently filtered Thames water when the river was in flood in the late autumn. Thus, at St. George's, Hanover Square, out of the sixty-five cases of enteric fever which had occurred in the district during 1894 no fewer than twenty-nine were notified in November and December and only fourteen in the three previous months, when the seasonal prevalence of the disease usually takes place.

The pollution of smaller tributaries from mansions, farms, and ditches is seldom prevented except in those cases where the river is under the control of an active authority, which has special powers conferred on it by Act of Parliament, as in the case of the Thames Conservancy.

In the lower reaches of rivers large quantities of sea water are carried up by the tides. As sea water contains a high proportion of salt (chloride of sodium), the amount of chlorine furnishes a measure of the admixture. By this test it has been found that at London Bridge the river contains about one-fourth

of sea water. The first effect is a considerable deposition of solid matters, due both to retardation by the tidal wave and to the precipitating action of salt water. Dr. P. Frankland finds that the influx of chlorides favours the multiplication of some bacteria to an extraordinary extent, especially the germs of cholera. The high percentage of salt (or chloride of potassium) in the Elbe may have accounted for the severity of the cholera epidemic at Hamburg. In London also during some of the earlier outbreaks, the East London supply, where the disease was most fatal, was mainly derived from the tidal portion of the Thames. Brackish waters from the estuaries of rivers, as well as those drawn from the gravel near the sea (except from the occasional fresh-water springs, p. 65), are quite unfit for drinking, apart from bacteriological reasons, on account of the large amount of sodium and magnesium chloride, which render them purgative and unwholesome. Waters containing even a small amount of sodium chloride are therefore always unsuitable for drinking purposes.

The measurement of the volume of flow of a river is easily understood in theory, but there are many practical difficulties. If the depth and width of the river be found, the transverse section can be plotted, and the area found by ruling squares on the drawing. A great number of such sections being made, an average is obtained in square feet. The mean velocity is then determined by boards sunk at different depths attached to floats. A series of observations being made, the average rate of flow in feet per hour is obtained. This, multiplied by the average sectional area, gives the number of cubic feet of water passing per hour. To calculate into gallons, 6·25 gallons equal 1 cubic foot. The average daily flow of the river Thames at Ditton is 906,000,000 gallons, of the Severn 300,000,000, the Ouse at York 140,000,000, the Tiber at Rome—a very rapid river —5,500,000,000.

It may be generally stated that the water supply of towns should not be taken from rivers if it can be avoided. The unfiltered water of rivers is never safe to drink, especially in their lower portions, where many of them, as shown by their appearance and odour, are practically open sewers. In the Seine, where numbers of wash-houses for linen are established on the banks and in the stream, Miquel found that the river water, containing originally 10,000 bacteria in one cubic centimetre, contained no less than 20,000,000 after passing through a wash-house, and many of these organisms would be of the more dangerous class.

There are a large number of rivers throughout the country furnishing water for domestic purposes which are scarcely ever examined by chemical or bacteriological analyses. The purity of sewage effluents and the character of the discharges from factories are occasionally examined by local authorities, but usually

not until a complaint is made. The existing Acts having to a great extent failed in operation, it must be laid down as a sanitary necessity, if rivers are to be used for any water supply, that a regular system of inspection by officers of the Local Government Board be established, similar to the existing system under the Alkali Works Regulation Act, 1884, with regard to the purity of air.

In respect to the London supplies from the Thames, in which much more care is taken, there is some divergence of opinion. The Royal Commissioners of 1892 reported as follows: "We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of excellence and of purity, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and the Lea because these rivers are liable to pollution, however perfect the subsequent purification, either by natural or artificial means, may be; but having regard to the experience of London during the last thirty years and to the evidence given to us on the subject, we do not believe that any danger exists of the spread of disease by the use of this water, *provided that there is adequate storage, and that the water is efficiently filtered before delivery to the consumers*. . . . . With respect to the quantity of water which can be obtained within the watersheds of the Thames and Lea, we are of opinion that, if the proposals we have recommended are adopted, a sufficient supply to meet the wants of the metropolis for a long time to come may be found without any prejudice to the claims or material injury to the interests of any districts outside the area of Greater London."

Dr. Edward Frankland, in his lecture at the Royal Institution in February, 1896, supported this conclusion, and also stated that "not a single harmful organism had ever been discovered, even in the unfiltered river water as it entered the intakes of the various companies, although these organisms had been diligently sought for." This is partially explained by the difficulty of isolating them from such an immense volume of water, and of identifying them conclusively when found. Perhaps Mr. Dibdin's method (p. 17), worked on large quantities of water, may eventually succeed in discovering survivors of the typhoid and other pathogenic bacilli that undoubtedly enter the Thames. But the real reason is to be found in the fact proved by Dr. Percy Frankland and others, that unsterile surface water, like that of the Thames, possesses bactericidal powers irrespective of the further multiplication of any of the contained water-bacilli. He has, however, also proved that typhoid and other bacilli might, if of strong growth and in extra numbers, become habituated to their surroundings; and that, even if only a few remained, perhaps so scattered as to escape observation, they

would, when by chance introduced into a purer and naturally sterile or sterilised water, recommence multiplication with extraordinary vigour, so that in this way a severe epidemic might be occasioned.

The Report of the Royal Commission was by no means universally accepted by scientific men. Indeed, the highest medical and scientific opinions are practically at one in stating that the drinking water of a populous town ought not to be taken from rivers running through cultivated and inhabited lands. No fewer than three of the members of the recent Royal Commission were examined as experts on the Birmingham Water Bill in 1893, and they all expressed this view with more or less emphasis. No doubt, careful filtration will remove much impurity, but it is admitted that no system of filtering on a large scale can be relied on to remove all pollution. The Royal Commissioners themselves found serious fault with the filtering and reservoir arrangements of some companies. It is well known to any analyst who has examined daily samples of London waters that most of the companies supply at intervals, and invariably at times of flood, water that is more or less turbid, and therefore has not been efficiently filtered. And it is obvious that where suspended visible matter is present the more subtle bacteria may also certainly penetrate.

In favour of the proposed supply from Wales, which will be described in Chapter VI., p. 121, it may be pointed out that the present Thames system not only robs the other towns of the Thames Valley for the benefit of London, but subjects them to a heavy expense in treating their sewage.

The average daily supply from the Thames during November, 1895, was about 123,000,000 gallons; from the Lea, 45,000,000; from springs and wells, 42,000,000: being in the proportions of fifty-nine Thames, twenty-one Lea, and twenty from springs and wells.

The amount of solid matter carried down by rivers is frequently enormous. The Mississippi has been calculated to carry down 400,000,000 tons of suspended matter yearly; the Ganges over 6,000,000; the Thames about 2,000,000.

CHAPTER VI.

STORAGE—FILTRATION.

It has been already stated that all the varieties of water on the earth's surface have originally fallen as rain. The fluctuations of seasons affect the volume of rivers and of every spring that is not fed by a large underground "pocket" of water, or a system of extensive fissures, as in the chalk. Storage of water then becomes necessary. In some localities nature has effected this by means of lakes, sometimes of vast extent, as in Canada and Central Africa. Where fed by mountain streams they have the character of upland surface water, as described on page 61, with the further advantage, when the lake is large, that it has undergone a long subsequent purification by subsidence and oxidation, so that it often attains a high degree of clearness and of organic purity. Most of the chief towns in the North of England derive at least part of their supply from mountain lakes, either natural or artificial. On account of their distance from contamination, and of their great depth permitting the solid particles to subside beyond the reach of disturbance, such water is fit for consumption without filtration, the only precaution being to keep the long aqueducts watertight and free from organic