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# WATER AND ITS PURIFICATION

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*A HANDBOOK FOR THE USE OF LOCAL AUTHORITIES SANITARY OFFICERS, AND OTHERS INTERESTED IN WATER SUPPLY*

BY

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WITH NUMEROUS ILLUSTRATIONS AND TABLES

Capio Lumen

LONDON
CROSBY LOCKWOOD AND SON
7 STATIONERS' HALL COURT, LUDGATE HILL
1897

BRADBURY, AGNEW, AND CO. LD., PRINTERS,
LONDON AND TONBRIDGE.



# PREFACE.

THE purity of water supplies has always been a subject of importance, and every year receives more and more attention. Not only in London—where the present public supply has been recently discussed by a Royal Commission and by various other bodies—but also in several provincial towns, the desirability of a public supply of greater purity and larger quantity is now under consideration; while in the rural districts outbreaks of disease have now so frequently been traced directly to polluted wells, that it can safely be said that at the present time the question of universal pure drinking water is one of primary importance to all classes of the community. The closing of polluted wells, and decisions on new supplies, are now, however, in the hands of the general public, who, and their elected representatives, thus need to become acquainted with the results of the progress made during the last few years in bacteriology and knowledge of the causation of disease.

To all who are interested in the subject of Water Supply this book is meant to appeal, and it is hoped that by its perusal some insight into the methods of research and the interpretation of results will be attained.

Reports of the results of water analysis are too often regarded as being of too technical a nature to be practically useful; whereas, on the contrary, such reports should at least indicate to the reader in what direction alterations, if necessary, in the present conditions of supply should proceed.

With this object in view, I have endeavoured to include in the scope of the book the more recent conclusions which have been arrived at by workers in different branches of the subject, and have as far as possible refrained from details. Whilst it is necessary that the results of a chemical or bacteriological analysis of a sample of water should be intelligible to a non-professional reader, it need hardly be pointed out that it is impossible for any but those who have been trained in the methods of analysis to arrive at results which are worthy of confidence. This little book will have achieved an important result if it tends to make more generally known the fact how valueless—and, moreover, how dangerous—it is to rely upon so-called rough-and-ready tests for forming an opinion upon the purity of a doubtful water.

In preparing the volume, I have had the advantage of several important suggestions from my friend Mr. Henry Law, M.Inst.C.E., who also was good enough to



read the proof-sheets as they were passing through the press. My thanks are also due to my assistant Mr. C. G. Stewart, F.I.C., for his valuable help, and to those publishers, manufacturers, and others, who have kindly lent blocks for illustration.

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28, Victoria Street, Westminster.
*December*, 1896.

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## CHAPTER I.

### *CHARACTERS OF NATURAL WATERS.*

THE word "pure," as applied to water for human use, bears a meaning different from the strict scientific sense. Chemically pure water—that is, the compound of oxygen and hydrogen ($H_2O$)—like chemically pure iron, is only to be obtained by laboratory processes and with great difficulty; and as it dissolves and absorbs a varying quantity of most matters with which it comes in contact, its preservation in the pure state presents an equal difficulty. For drinking, cleansing, and manufacturing purposes it is not necessary, nor is it always advisable, that it should be pure to this extent. It is sufficient that it should be as far as possible devoid of matters that would be injurious to health or prejudicial to commercial purposes. Such water has in most inhabited countries been plentifully supplied by nature, and the object of human effort must be, firstly, to select the best among the many supplies by studying the nature of the substances that are usually found naturally admixed in more or less quantity with all waters, and, secondly, to secure that a good water shall be transmitted to the consumer without any diminution in its practical purity. When we examine a sample of water in a glass, we take notice of its appearance and colour, whether bright or dull, clear or turbid, brownish, greenish, or colourless; then its odour: if it possesses any, common consent rejects it as bad; afterwards its taste, flat, brisk, or saline: an educated palate distinguishes a great difference between natural waters in this respect. But these characters, called "physical," or appreciable to the senses, are by no means conclusive nor even safe in application.

Taste has many times proved a very deceptive test. Water from wells in towns is frequently bright, sparkling, and piquant to the taste, owing to the nitrates and other salts it has derived from the soil. It has often been preferred by the residents to a purer town supply, even where cheapness was not a consideration. When such wells and pumps have been ordered to be closed by the sanitary authority, considerable opposition has often been encountered from the inhabitants. The well-known case of Broad Street (London) pump, the water of which was generally popular in the neighbourhood, is a significant instance. During a cholera outbreak, this infected source, bright and sparkling as it was, carried the disease to a number of fatal cases, whilst other residents in the locality who happened to make use of a different supply were not attacked.



Moreover, a lady who formerly lived in the district, through preference for the brilliant character of the water had it conveyed in bottles to her house at Hampstead for her own consumption, and a comparatively isolated outbreak occurred in her establishment, with fatal results. Favourite drinking waters of this kind have often been directly traced to springs originating from graveyards. Both by chemical and biological examination, and by the results in spreading disease, the most serious pollution by decaying animal matters has repeatedly been demonstrated. On the other hand, flat, insipid, and even cloudy waters have caused no injury in use, their faults having been due to causes which had no hygienic significance. It is impossible, therefore, to adequately judge of the wholesomeness of a water by its physical characteristics.

The odour, however, is often of value as an indication of the source. It may be peaty from upland sources, marshy (there is a distinction between the two) from rivers, swamps, and ponds, sulphuretted or even urinous from recent sewage contamination. The odour is best observed by half filling a stoppered bottle (a cork is inadmissible, as by itself it imparts some odour) with the water, warming to blood heat (about 100° F.), shaking vigorously with the stopper slightly loosened to relieve the pressure of the gas, and smelling carefully, preferably in comparison with a pure water, warmed to the same degree. The natural odour of pure warmed water is very slight. A mere trace of urine would at once be detected by this test, and would, of course, condemn the water and render necessary a rigorous investigation as to its source.

Crookes, Odling, and Tidy, in some of their London water reports, speak of an "evanescent smoky taste." This, though certainly possible in the water of a smoky town, is not of frequent occurrence. A kind of fishy taste and odour, due probably to the presence of trimethylamine, is sometimes produced by the bacteria attending putrefaction. Many of the infusoria cause peculiar unpleasant flavours; earthy and "vegetable" ones are often communicated by larger living aquatic plants, and mouldy tastes and smells by fungi. People who are habituated to their use consume waters so impregnated with impunity, but they may undoubtedly cause nausea and other ill effects in those not accustomed to them, and the unusual flavours are obviously an evidence of something that ought not to be there.

The colour is observed by looking at a brightly illuminated surface through a column of the water two feet in depth contained in a tube or narrow jar of colourless glass, or more simply by setting a thin tumbler of the water on a sheet of white paper in a good light. Pure water has naturally a bluish tint. A greenish colour generally denotes the presence of microscopic water plants (algæ), while the water from rivers and ponds is usually more or less brownish and turbid. A yellowish tint points to the possible presence of urine.



Comparison should always be made with a pure water when available. Clearness is judged at the same time, but perfect clearness can only be ascertained by careful experiments, as many waters which appear limpid to the eye contain an appreciable amount of invisible solid matter in suspension. Such microscopical solid matter and many organisms are so transparent that their presence can only be proved by filtration.

Classification of the Constituents and Impurities of Waters.

| | | | |
|---|---|---|---|
| Suspended or insoluble | Living | Animals | Fish, worms and their eggs, acari, crustaceans, insects, infusoria, &c. |
| | | Plants | Algæ; moulds; fungi; bacteria. |
| | Not living | Mineral | Clay, sand, chalk, soot, oxides of iron, and occasional manganese. |
| | | Vegetable | Hairs; vessels; fibrous and cellular tissue more or less decayed; starch, and pollen granules; fibres of paper and clothing. |
| | | Animal | Hairs, epidermal and epithelial scales, fibres of meat, &c.; fæcal matter; portions of insects; dead animalculæ. |

The grosser suspended matter in a water can be removed by filtration or subsidence, whilst that dissolved is not affected by such treatment. The substances in solution are therefore a better indication of the permanent character of the water, and consist of a great variety of bodies, as shown by the following table:—

DISSOLVED MATTERS.

| | | |
|---|---|---|
| *Organic solids* | | Peaty and other vegetable matter, urea and other constituents of excreta and animal fluids, albuminoid substances, products of putrefaction, as alkaloids (ptomaïnes) and amido-acids, phenol and its derivatives, with waste products from factories such as fat, soap, oils, tar, colouring matters, &c., sulphocyanides and benzene from gas works. |
| *Inorganic or mineral solids* | *Usual* (harmless unless quantity excessive) | Carbonates, chlorides, sulphates, nitrates of calcium, magnesium, sodium, potassium, iron, aluminium; silica and phosphates, with minute traces of other bodies and small quantities of ammonium salts. |
| | *Occasional* (generally extraneous and noxious) | Nitrites; poisonous metals: lead, iron (in excess), copper, zinc, arsenic, manganese, barium, strontium; medicinal salts containing iron, iodine, bromine, silica, boron, lithium, &c.; products of manufacture: mineral acids, alkalies, and salts. |
| *Gases* . . | . . | *Normal*—Oxygen; nitrogen; carbon dioxide. *Abnormal*—Sulphuretted hydrogen, sulphur dioxide, ammonia, &c. |

*The Dissolved Organic Matter.*—All organic matter is objectionable, as it is necessarily a sign of contamination. But the quantity of organic matter is not so important as the quality. For instance, an upland water may contain a large quantity of brown humous matter, almost entirely carbonaceous; yet, beyond being slightly astringent or laxative, according to the nature of the organic matter it has absorbed, it will not convey disease. On the other hand, a bright, clear water with less organic contents may include such dangerous elements as will infect a whole neighbourhood with a fatal epidemic. But the peaty water is not therefore to be approved; it contains abundant



food for the growth of organisms that may accidentally enter. It must be purified by oxidation or precipitation before being passed as potable. There is another objection to peaty waters: they are usually acid from the presence of humic (*humus*, the ground), crenic and apocrenic, and other brown vegetable acids produced by the decay of vegetable matters. These waters have a tendency to dissolve metals, rapidly corroding iron, and therefore are unfit for use in steam boilers. They also attack lead pipes, and thus render the water poisonous. Their colour alone makes them unfit for many technical purposes. Fortunately they can be easily and cheaply improved by a method which will be described later (p. 141).

As François Coreil says (*L'Eau Potable*, Baillière, Paris, 1896, p. 11):—" Waters charged with organic matters can create true symptoms of poisoning, although they are incapable of producing specific maladies if they do not contain the specific germs of the disease."

Hippocrates drew attention to the bad state of body occasioned by drinking impure waters. The effect of marshy waters in causing ague, dysentery, &c. is so well recognised that the term "paludism" has been introduced for it.

Animal organic matter of recent origin and undergoing rapid change is always looked upon as doubly dangerous. It may be reduced by putrefaction, carried on by bacteria, into simpler and less noxious chemical products, which are still, however, organic and nitrogenous. Some of these are of an alkaloidal nature, or allied to ammonia, and are called cadaveric alkaloids, or "ptomaïnes," "toxines," or "septic ferments," and are exceedingly poisonous. They will still be present in waters which have been freed from bacteria by filtration, so that a filtered polluted water may yet be unwholesome. It is believed, however, that further bacterial action can convert such compounds into ammonia, which is in itself a harmless constituent of waters.

Finally, the ammonia, with the aid of atmospheric oxygen and of bacteria, is converted into nitrates, which also convey no marked toxic influence. This is what is meant by the natural purification of water, and forms a most important factor in dealing with water supplies. Recent excrementitious matter sometimes enters into waters through leaky pipes or wells being situated close to closets. In country villages it was formerly common to see closets on the banks of brooks discharging directly into the stream, the water of which was actually drunk by people living lower down before there had been time for oxidation or natural purification to take place. Such conditions have caused many violent epidemics, notably the one at Terling, in Essex. This form of pollution is easily recognisable by the odour, fæcal or urinous, produced on warming the water. The urea present in the urine may sometimes be detected in such waters, but it



rapidly passes into carbonate of ammonia. Phenol, or carbolic acid, is said to be a constant constituent of sewage, and a test for the presence of soluble animal matter in waters is founded on its detection. It has been proved that water polluted by fæcal matter can be drunk for a time with impunity by persons in health. This fact, together with the immunity of many individuals from certain forms of infection, probably accounts for the escape from apparent consequences for long periods of persons who have habitually made use of wells and streams which were obviously contaminated with excreta, a fact which has often been adduced by unthinking persons in order to throw doubt on the importance of securing a purer water supply. But, apart from the repulsiveness of the idea, the immunity may at any time be terminated by the passage into the water by the same channel of special pathogenic organisms.

The nature and amount of the mineral salts present in water will depend on the rocks or soils over which it has passed or through which it has percolated. Almost all mineral matters are soluble in, or acted on by, water and air; therefore the amount dissolved will depend on the amount present, solubility, time of contact—*i.e.*, whether the current is slow or fast—and on the presence of accessories like oxygen or carbonic acid. The mineral constituent which is usually present in largest quantities is calcium carbonate, dissolved by the carbonic acid in the water as bicarbonate. Magnesium carbonate is acted on in a similar manner, and the chloride, sulphate, and nitrate of these two metals are generally to be found in natural waters. These earthy salts cause "hardness," and will be discussed in Chapter X. It is sufficient to say that in moderate quantities they seem to make no difference to health. But, on the other hand, goitre has been suspected to be occasioned by waters containing a large amount of these salts, and constipation and dyspepsia are known to be sometimes produced by very hard water. Waters containing large quantities of magnesium salts or sulphate of soda are purgative, and frequently cause diarrhœa. Potassium salts are not usually present in any quantity, except in sewage-polluted waters.

Common salt (NaCl) is a frequent constituent of waters found near the sea or brackish estuaries, but unless it can be traced to a marine origin or is derived from rocks like the new red sandstone, which contain deposits of salt and brine springs, its presence in quantity is indicative of animal contamination.

Natural waters are usually faintly alkaline from the presence of carbonate of lime, and at the same time are acid to phenolphthalein, owing to free carbonic acid also being present. Any other acid or alkaline constituent would render the water injurious to digestion. It is found by experience that certain proportions of mineral salts are beneficial in waters; beyond these proportions they may be injurious and



deteriorate the water for most purposes. The approximate limits will be considered in a subsequent chapter.

Ammonia ($NH_3$) and its salts are almost entirely absent from pure waters. Ammonia, being one of the final products of the decomposition of animal matter, is a very sure indication of pollution, and frequently indicates contamination by urine. It, however, is comparatively easily oxidised by water organisms into nitrites and nitrates. Its relation to these compounds is further discussed in a later section.

All waters contain minute traces of iron. Its presence in amount as low as one-fifth grain per gallon imparts a disagreeable chalybeate taste to the water, and renders it unfit for general consumption and most industrial purposes. It is, however, easily removed by precipitation with lime and oxidation (p. 168), and the water so purified contains less bacteria, but generally has still a somewhat unpleasant taste. For this reason it is rarely economical to resort to the purification of mine and pit waters or those derived from ferruginous strata.

Silica ($SiO_2$), derived from the passage of the water over sand, flints, or quartz rocks, is always present in waters, but is frequently overlooked. It often amounts to one grain or more per gallon, and is precipitated with the earthy carbonates on boiling. In very soft waters, such as those which are derived from the uplands of igneous rocks, the silica in a gelatinous form constitutes the major portion of the precipitate on boiling. It is present in considerable amount in boiler incrustations, especially those from sea water (Table B). If in unusual quantity, it is a bad feature for industrial waters, though for medicinal use it may be of value.

Salts which give a water a medicinal value, and contaminations from manufactures, are considered in a subsequent chapter.

Even traces of poisonous metals condemn a water at once. Lead especially is known to accumulate in the system and occasion paralysis and other serious effects (p. 135). Although many of the metals can be removed from a water by filtration through animal charcoal, the action cannot be trusted, so that, unless the source of the metal can be detected and the contamination stopped, it is imperative that the supply should be disused for drinking.

A water to be palatable should be fully aerated; *i.e.*, it should contain fairly full amounts of the natural constituents of the atmosphere, oxygen, nitrogen, and carbonic acid, otherwise it tastes flat and insipid. Deep waters have, as a rule, a larger quantity of nitrogen and less oxygen. Dissolved oxygen is necessary for fish life, and also for the self-purification of rivers, since it oxidises the organic impurities they contain. River water on boiling gives off about one-twentieth of its bulk of a mixture of oxygen, nitrogen,



and carbonic acid. Water can dissolve at ordinary temperatures about its own volume of carbonic acid, 3 per cent. of oxygen, and $1\frac{1}{2}$ of nitrogen. Some waters in the Pyrenees evolve much nitrogen, and argon has been recently found to be one of the gaseous constituents of such waters. Whether argon and helium are present in other waters, or whether they have any importance in relation to health, remains to be ascertained.

Sulphuretted hydrogen and sulphurous acid are only naturally present in mineral springs, the former constituting hepatic and the latter "sulphurous" waters. Certain organisms, such as beggiatoa, the sewage fungus, and others, are capable of reducing the natural sulphates to sulphides, and the water then becomes foul and unfit for drinking; this action occasionally takes place in waters sent for analysis which have been kept too long in closed bottles, and is an indication of organic matter of a very objectionable kind. The presence of sulphuretted hydrogen is at once revealed by an odour of rotten eggs and an unpleasant hepatic taste.

Suspended particles, if of an appreciable size, soon sink to the bottom and constitute a sediment, from which the water may be poured off in a clear state. In depositing, the suspended matter may carry down with it most of the minute animals, algæ, and even bacteria, so that an examination of this deposit by the microscope is of great value in revealing the nature of the solid impurities present. By such deposition rivers become to a certain extent purified in the quieter tracts of their flow, and become clear, although the silt or sediment is apt to be again raised by an unusual current, causing "storm water" to be always more or less turbid, as is seen at intervals in many of the London supplies derived from the Thames. The colour and character of the suspended impurities may be judged by looking at a considerable volume of the water alternately before a bright light, as a window, and a dark surface, such as cloth. Contrary to general opinion, most suspended particles in moderate quantity do not affect the flavour of the water, as can be proved by tasting in the dark a water which is "thick" and one that is perfectly clear. But, besides being unsightly, they afford evidence that the water has not been efficiently filtered, and it is mainly for this reason that a turbid water is condemned. Finely divided mineral matter in suspension is believed by some to be a cause of intestinal irritation and diarrhœa. Clarification can in most cases be effected by dissolving in it a small quantity of alum, from one to six grains per gallon, afterwards adding the equivalent amount of carbonate of soda (see p. 147) and allowing the gelatinous precipitate of hydrate of alumina, which carries down with it the suspended matter, to subside. Such a process must be carried out with care, as its success depends on the character of the water, and if more



than the requisite quantity of either reagent be used, the liquid will be rendered unfit for drinking. The water should always be poured off directly the deposition is complete, as the bacteria and other organisms commence to multiply very rapidly when in such close contact with their food, and will then re-enter the water, making its condition worse than before.

It is obvious that there are two kinds of insoluble or suspended matters, inorganic or mineral and organic, the latter being of either animal or vegetable nature and either living or dead. Organic matters, from being lighter, would be supposed to remain longer in suspension than mineral matters; but the very minute particles of clay, and in a less degree those of chalk, are exceedingly slow in subsiding, so that clayey waters remain for a long time turbid. Such waters are very difficult to clarify, and rapidly clog the pores of any filter.

Particles of soot are somewhat frequent in the water of towns, and are an indication that the water has not been sufficiently protected from atmospheric dust, or that an admixture with rainwater has occurred. Oxide of iron may be recognised in a sediment by its rusty colour; it is common in waters derived from the clay, and is not a good sign if present in more than minute quantities. Moreover, it renders the water unfit for washing and for several industrial purposes. Minute crystals of carbonate of lime are frequent in hard waters, such as those from the chalk; these and angular fragments of sand are easily distinguished under the microscope. They rapidly settle, and are only of importance as showing the water to be derived from calcareous or siliceous rocks.

*Methods of collecting the Sediment.*—About a gallon of the water is allowed to stand, carefully pouring off the top and transferring the lees to a conical glass. On settling, the deposit may be dipped out with a small pipette or glass tube drawn to a point; the drop containing the sediment may then be placed on a glass slide between two slips of gummed paper (to allow room for the water), a cover glass placed over, and finally examined under the microscope. Portions should be tested with dilute hydrochloric acid (carbonate of lime dissolves with effervescence; oxide of iron dissolves with a yellow colour in stronger acid; sand is not affected) and with iodine (starch turns dark blue; animal matters are generally dyed brown). Bacteria may be stained with aniline dyes, such as methylene blue, methyl violet, or fuchsine.

Mr. Dibdin, the chemist to the London County Council, has pointed out that the sediment by no means represents all the solid matters in water, that a good deal settles on the sloping sides of the glass, and that many moving organisms remain suspended. He has introduced a method by which the whole of



the insoluble matter is collected and measured. A litre (1·76 pints) of the water, or less if it be of bad character, is filtered through one of the smooth "hard filter papers" now commonly used in laboratories, and the deposit washed into a "micro-filter." This is a glass tube drawn out for some distance to a diameter of two millimetres (0·078 inch), and closed at the bottom by a porous plug of baked clay. The sediment settles on the plug, when the water is drawn off by a vacuum, and its depth is recorded in millimetres. The lower part of the tube is then cut off, and the deposit transferred to a glass slide, and examined under the microscope. By this treatment waters usually returned as "clear, no sediment," often show a large and varied deposit. So delicate is the method that the presence of most objectionable matters has been repeatedly demonstrated in a single tumblerful of so-called good drinking water. Water from chalk wells only yields a minute quantity of deposit, consisting of a few infusoria, fibres, and debris. Blank experiments with pure water yielded only a minute quantity of fibre, and occasionally a few starch granules from the filter paper.

It need hardly be said that in all these inquiries the greatest care must be taken to exclude dust. Samples should be taken in perfectly clean stoppered bottles, and if from a tap it should be allowed to run for some time, and the bottle washed out with the water. From rivers and pools the water sample must be collected some distance from the shore by sinking the bottle and then withdrawing the stopper, so as not to collect any substances which may be floating on the surface. As bits of duckweed, straw, &c., would make a great difference in the percentage amount of suspended matter found by this method, it is important that they should be either excluded when taking the sample or removed mechanically before analysis.

## CHAPTER II.

### *ANIMAL AND VEGETABLE IMPURITIES.*

EVEN in these days, when the importance of the laws of health is so generally recognised, and the nature and causes of disease are receiving every day fresh light, we are occasionally confronted with the argument that a water condemned by chemists and bacteriologists cannot be so dangerous as it is represented, since it has been drunk by many people with apparent impunity, or at any rate with no direct production of disease.

It would hardly be worth while to combat such a contention, in the face of the opposite propositions that have been demonstrated by recent visitations of cholera and by the periodic severe outbreaks of typhoid and other water-borne diseases, were it not that the argument is constantly used to fortify the objection of expense, with the effect of quashing or delaying local schemes for obtaining a proper supply of pure water.

M. Monod, Director of Public Health in France, examined the mortality of twenty-four towns for two years before and two after they had been supplied with a purer water. In three there had been no change (perhaps the water had not been really improved), but in twenty-one it had been reduced