DEVELOPMENTS IN WATER TREATMENT—1

Edited by

W. M. LEWIS

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PREFACE

'Surveillance of Drinking Water Quality' published by WHO in 1976 in its introduction stated that 'Public health protection of drinking water supplies should assure that each component of the system—source, treatment, storage and distribution—functions without risk of failure'. Drinking water is perhaps, together with the air we breathe, a unique commodity in that the general population is normally permitted no freedom of choice, so the assurance that the water available for drinking is of the highest quality is of paramount importance.

Since the universal introduction of disinfecting agents in water supplies in developed countries, risks to health from microbially contaminated drinking water have been dramatically reduced. Today the problem confronting personnel responsible for ensuring the public's water supply is perhaps of a much more subtle character brought about, in part at least, by the rapid progress in analytical chemistry and the environmental awareness of the general public resulting in the demand for the creation of standards of quality for drinking water.

Chemicals present in raw water supply range from simple ions extracted from soil and minerals in the watershed to (in some instances) unidentified waste products from the chemical industry, the length of the list being limited only by the capabilities of the analytical chemists and their instruments.

Some medical researchers proclaim that the presence, or absence, of a certain substance in drinking water is directly associated with the differences in death rates from specific diseases or the incidence of morbidity. The problem is compounded due to the fact that the toxic effects of many identified chemicals are insufficiently understood. Thus the responsibility devolving upon the shoulders of personnel responsible for 'Treatment' is to provide a process (or combination of processes) which will ensure, as far as is practicable, that the water supply is not only aesthetically acceptable, but also of the best chemical standard and in a condition which will not damage the integrity of the distribution system which could result in subsequent and additional contamination. With rivers of the calibre of the Danube, Trent and Rhine, to mention but three, the resulting treatment, to provide drinking water whose quality is beyond suspicion, needs to be very sophisticated.

The 'treatment process' is not a single identifiable parameter but is dependent upon the nature and quality of the raw material and may for example involve only simple filtration or filtration plus disinfection. On the other hand if the quality of the supply water is from a lowland river, such as the three previously mentioned, then it follows that a combination of individual processes, commencing with coagulation for the removal of suspended matter, etc., and employing perhaps the majority of the techniques described, will be essential to provide the required quality of drinking water.

Within this series will be found the various important facets of treatment each written by an author, expert in the particular field, who has introduced his topic with a brief historical background before providing the reader with the most up-to-date information available on the subject.

It is a salutary thought that in 1975 (latest information available) some 78 % of the world's rural population and even 22 % of the urban population were without an adequate water supply. Of the urban population of the world having access to a piped water supply (77 %), 57 % only had house connections and 54 % of the population served by public piped supply received it only on an intermittent flow basis.

Conscious of the urgent need to rectify these shortcomings, the UN Water Conference—Mar del Plata, March 1977—urged the adoption of 'The International Drinking-Water Supply and Sanitation Decade, 1981–1990'. The aim of the latter is to encourage and assist all countries of the world to adopt programmes with realistic standards for both quality and quantity and to provide water to all people by 1990, if possible.

It is unfortunate, but nevertheless true that at present, and for how long into the future we know not, many countries—not only the developing ones—are experiencing financial constraints of varying magnitude. To achieve the above objectives will therefore strain the ingenuity and professional expertise of all concerned with the task of supplying the community with drinking water.

It is consequently singularly appropriate that these first two volumes on 'Developments in Water Treatment' should be available at this time, for within their pages will be found that information on 'Treatment', appropriate to the needs, to enable people to overcome the financial constraints laid upon them.

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POTABLE WATER QUALITY

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SUMMARY

Advances in knowledge of effects of constituents of water on human health have been made over the past century, and in moving in the developed countries from an era of water-borne diseases to one of reliance on wholesome water supplies which can be consumed safely there has been remarkable progress. However, the undeveloped countries suffer still from water-borne diseases, and the situation is put into perspective. The major developed countries have published water quality criteria, and these are compared and the relevant quality parameters are discussed. Where differences exist between the criteria, they are explained. Often there is criticism of inclusion of certain parameters, and where possible the reasons for such inclusions are given. The limitation of reliance upon criteria is referred to, and it is suggested that the final decisions on quality must rely upon the experience of experts in the field of water supply.

1.1. HISTORICAL SURVEY

1.1.1. Introduction

Our forebears probably learned by experience which springs or streams were suitable for drinking purposes. In some parts of the world today a source of water of any kind may be attractive if there is no alternative and the need is great. However in our civilised society potable water of an acceptable and reliable quality is demanded as a right. The concept of 'acceptable' changes with time as it becomes more obvious that there are constituents of water which may have an adverse effect upon the health of the consumers. Some sources of water, particularly those from underground sources, may be suitable for direct consumption without treatment, but the majority of surface waters require some form of treatment before they are considered as attractive and acceptable to the population. Both in order to decide upon the treatment necessary to produce such an acceptable water and to decide if the treatment applied has been sufficient it is necessary to compare the analysis of the waters with some standards.

From the consumer's view the water shall look attractive and generally this means that it shall be clear, free from obvious solid matter and usually of low colour. These subjective assessments of water quality may vary according to what the consumers have been used to and also according to the need. In a very dry arid country, water would be accepted readily which would not be accepted in another country where water resources are plentiful. However, to protect consumers from adverse effects more delicate assessment of water quality is necessary. It is doubtful if the consumers of the water from the Broad Street pump could see anything amiss, yet Dr John Snow realised that that water contained some agent which was responsible for the spread of the disease of cholera in the district.[1] Following his demonstration that the use of an alternative water supply reduced the incidence of disease, he went on with his classic study in epidemiology by demonstrating the difference in the health of consumers of two different water supplies, one contaminated with sewage and the other not so. Following his observations on the qualities of the water supplies of the Lambeth Company and of the Southwark and Vauxhall Company other studies of a similar kind were carried out by Robert Koch in comparing the water supplies of Hamburg and Altona. Although waters have been subjected to forms of filtration since early days, for it was recorded in Egyptian writing and also advocated by Hippocrates some 400 years BC, it was as a result of the work of Koch[2] that it was realised that filtration applied to remove suspended matter from water, and thus to render it more attractive in appearance, also had a beneficial effect in reducing the bacterial content of that water. Bacteriological standards have been accepted for a considerable time and it is extremely important that these are not neglected because more elegant chemical analyses seem to be becoming more prominent. It is estimated by the World Health Organisation that some 80% of all sickness and disease in the world is associated with water either directly through contamination with microbes or associated with vectors—for example, insect carriers and snail intermediate hosts—or failings in hygiene owing to an insufficient supply of water.[3] At any one time it is estimated that some 400 million people are suffering from gastro-enteritis and 200 million people suffer from schistosomiasis, both probably related to contaminated water used for consumption. Increasing re-use of water in the developed countries means that the risks of the presence of some pathogenic organisms can become greater.[4] The practice of disinfection of public water supplies in the developed countries has become almost universal since the use of chlorine was introduced for this purpose in 1908. Although for a considerable time, some sources of water were considered to be protected from pollution sufficiently that it was not necessary to disinfect that water, the typhoid epidemic in Croydon in 1937[5] indicated that even underground sources of water were not completely safe from contamination, and in the United Kingdom disinfection of water supplies is now applied to all but the smallest sources supplying small communities, and with the development of means of disinfecting these it is expected that almost all these will be disinfected in the near future.

1.1.2. Guidelines for Quality Control

Chemical contamination of potable water supplies could make itself obvious by discoloration upon standing of the water exposed to the air in the case of iron or manganese, in bitterness or other astringency, from its effect as would be evidenced by an excessive content of magnesium sulphate as an aperient; but in recent times the most dramatic indication of the effects of an unseen and unexpected contaminant came with the itai-itai disease in Japan owing to the water resources being contaminated by discharges of cadmium waste.[6] In the United Kingdom protection of water resources has been allowed for in various legislative Acts, principally those of the Rivers (Prevention of Pollution) Acts 1951 and 1961, the Water Resources Act 1963, culminating in the Water Act 1973. These have allowed control over discharges of industrial wastes into rivers to secure potable water resources. However it is not possible to prevent accidental releases of polluting substances and some 2300 such incidents on roadways have been reported in a year. Some of these had a potential of reaching water courses used for potable water supplies, but because of the vigilance of the authorities there have been no instances where the supplies to the public have been affected seriously.

For many years the main requirement for the quality of a public potable water supply has been that it should be wholesome, although this has never been defined. Under the various Public Health Acts the responsibility for ensuring that a supply of water to a community was wholesome has been vested in the local Medical Officer of Health, until the reorganisation of local authorities in England and Wales in 1974 and in Scotland in 1975 when the responsibility became that of the Environmental Health Officer. It would have been for the Medical Officer of Health to have declared that a water was unwholesome if he was not satisfied with some aspect of it. To provide guidelines, the former Ministry of Health published in 1934 a Report on the Bacteriological Examination of Water Supplies which was revised at intervals until the current edition in the series Reports on Public Health and Medical Subjects No. 71, the Bacteriological Examination of Water Supplies published by the Department of Health and Social Security, the Welsh Office and the Ministry of Housing and Local Government in 1969. This in its turn is being revised and will probably be extended to include sections on virus content of water and consideration of pathogenic protozoa. As far as the chemical constituents of potable water supplies are concerned the United Kingdom did not have a national standard. Individual water undertakings could refer to other published water quality criteria[7] until the World Health Organisation published its International Standards for Drinking Water in 1958. These were published as an aid to the improvement of water quality and treatment. They were not adopted officially in the UK. In 1961 the World Health Organisation published its European Standards for Drinking Water[8] with the object of stimulating improvement in drinking water quality and of encouraging countries of advanced economic and technological capability in Europe to attain higher standards than those referred to in the International Standard. It was accepted that because of the density of industrial development and of intensive agriculture in some European countries there were hazards to water supplies not always encountered in other parts of the world. Hence stricter standards were justified. Most water undertakings took note of the recommendations in the European Standards.

After the entry of the United Kingdom into the European Economic Community, the Commission of the Community became deeply involved in promotion of Directives designed to improve the quality of water supplies throughout the Community. The first of these to be completed and published was that concerned with the Quality of Surface Water Abstracted for Potable Water Supply.[9] Upon the acceptance of this directive by the Council of Ministers the United Kingdom was obliged to implement the terms and hence the standards in the annex to this directive have become official in the United Kingdom. A further draft Directive relating to the Quality of Water for Human Consumption has been discussed at length and was forwarded to the Council of Ministers on 31 July 1975.[10] There have been further negotiations on the terms of this Directive and it was accepted by the Council of Ministers in December 1978 but to date the definitive text has not been published. This Directive lays down standards for drinking water supplies for both the public and private sources in the Member States including the UK. These standards include not only those organoleptic requirements necessary to satisfy consumers, but standards for mineral constituents and for organic compounds. Whilst some of these parameters have been included normally in so-called sanitary analysis of water in order to determine whether or not there has been some degree of pollution, many of the less common elements have been included in the standards. Partly this is due to attention directed to their presence as a result of their detection, identification and estimation by the recently introduced elegant methods of separation and analysis including Thin-Layer Chromatography, High-Pressure Liquid Chromatography, Emission Spectroscopy, and for organic compounds the use of Gas Chromatography and Mass Spectroscopy. Concentrations of the order of parts per billion have been determined. The Commission of the European Community also arranges for research to be conducted in Member States and by collaborative work a long list of organic compounds found in waters has been published.[11] This list included several hundred compounds identified and estimated in drinking waters, and since the time of that publication very many more have been discovered.

The ability to detect and estimate elements and compounds down to such low levels has introduced a completely new situation into the public health field. The relationship between exposure in some way to very low concentrations of elements or compounds and some adverse effect upon health is a matter of serious study and in many instances it has been shown that the exposure over a very long period of time can in the end result in an effect. The period of time can be extreme for it is believed that some substances known to be carcinogenic may take up to 20 years after the initial exposure before effects are revealed. This is a vastly different position to the acute effects of larger concentrations of substances in water which have an adverse or a toxic effect within a comparatively short time, such as the bacterial contaminations with serious consequences in the recent past. The means of indicating whether a substance produces in some people a significant effect after a long time—that is, a chronic exposure—is to study the health of a whole population of a district exposed to this substance over the sort of period expected for induction of effects, and to compare the health statistics of that population with those of a similar population believed not to have been exposed to the substance. Corrections for different social, environmental and other factors have to be made, but if after this there are still significant differences in the health of the two populations studied there can be an indication that there is a relationship between exposure to the substance and a particular effect upon health. Such epidemiological studies are being employed increasingly in the search for logical reasons for imposing limits for constituents of water. An early example of the use of such studies was in the high incidence of thyroid disease in the region around the Great Lakes of North America including part of the Canadian province of Ontario. The low iodine content of local drinking water was understood to be an index of the deficit of iodine in the area. In the case of most minerals it is rare that water is the sole source in the diet but in the case of many it can provide a substantial proportion of the intake of that mineral. Thus it was so in the case of iodine. Another example of epidemiological studies revealing a deficit in normal intake is in the case of fluoride and the incidence of dental caries.

Unfortunately epidemiological studies can be long and painstaking and many other limits have been proposed in standards on the basis of shorter studies of relatively small numbers of people in particular situations, which result in published reports, the value of which may be doubted by other authorities. In cases of doubt about public health matters it is better to err on the side of safety, and so note is taken of these published reports until the matter of doubt can be resolved. Convincing proof one way or the other is often difficult to obtain and so such limits are included in water quality criteria as a precautionary measure. It is a matter of judgement in considering the analysis of a particular water supply whether it is necessary to determine such a constituent or not. It is to help those judgements that the parameters revealed in many water quality criteria will be discussed in the following paragraphs.

The World Health Organisation publication European Standards for Drinking Water[8] differentiates carefully between those substances which may be considered toxic at the concentrations likely to be found in drinking water and which are likely to give rise to actual danger to health, those substances which if present in excessive amounts may give rise to trouble (which may vary from objectionable taste to discoloration or turbidity), and those substances which may give some gastro-intestinal irritation which is nevertheless comparatively harmless. The standards also listed levels of substances which should preferably be controlled either because they could interfere with other treatment processes or cause corrosion or lay down an excessive amount of deposit. This concept has been perpetuated in the Directive on the Quality of Surface Water Abstracted for Potable Supplies. In this, those parameters which have a significant effect upon public health have been designated 'I' (for imperative) values whilst those which need to be considered from the point of view of nuisance values or peripheral effects upon health are given a 'G' (for guide) value. In the draft Directive on the Quality of Water for Human Consumption the 'I' value of the surface water Directive is replaced by a Maximum Acceptable Concentration (MAC) and the guide values also remain.

It is important to note that, in the Directive on the Quality of Surface Water, values are for the water sources. Some of the parameters quoted are indicators of the degree of pollution and have reduced values after appropriate treatment while others are conservative substances and are not changed materially during the treatment. In the case of others, allowance has to be made for an increase in their value as a result of treatment—for example; the sulphate level has to allow for the addition of sulphate when water is coagulated using aluminium or iron sulphates as coagulants. Three levels of water quality are shown corresponding to the three levels of treatment given in Annex 1 of the Directive as shown here.

ANNEX 1

Definition of the Standard Methods of Treatment for Transforming Surface Water of Categories A1, A2 and A3 into Drinking Water.

Category A1

Simple physical treatment and disinfection, e.g. rapid filtration and disinfection.

Category A2

Normal physical treatment, chemical treatment and disinfection, e.g. pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination).

Category A3

Intensive physical and chemical treatment, extended treatment and disinfection, e.g. chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination).

Another set of water quality guidelines has been published in National

Interim Primary Drinking Water Standards as required by section 1412 of the Safe Drinking Water Act (PUP.L.93-523) of the United States.[12] After giving details of the application of these standards, reference is made to maximum contaminant levels. There are also guidelines on the frequency of sampling, and guidance is given as to the methods of analysis to be used for the various contaminants. Reference will be made to the maximum contaminant levels in the standards in discussing the particular parameters.

It has been claimed that the first standards for drinking water quality in Europe were made in the USSR in 1937. They have been brought up to date and a new standard GOST 2874-73 is available[13] and follows a similar pattern to that of the World Health Organisation guidelines. Possibly the Soviet standards go further in accepting that there is a likelihood that several substances present simultaneously in water will enhance the total harmfulness. To prevent the increased risk from their combined action the limitation of chemical factors at low concentrations is based on the principle of summing the action of these substances. For a mains drinking water it is required that the sum total of substances expressed as proportions of the maximum permissible concentrations should not be greater than unity, i.e. $c1/C1 + c2/C2 + \cdots$ leading to c^N/C^N shall be less than or equal to 1, where $c1, c2 \ldots$ up to c^N are concentrations found in the water expressed as mg/litre and $C1, C2 \ldots$ to C^N are the standard maximum permissible concentrations in mg/litre. The parameters excepted from this form of mathematical treatment are fluorine, nitrates and radioactive substances. The method of assessing bacteriological composition has been brought into line with those of the WHO standards.

There is an important point to be considered when comparisons are made between published water quality criteria or guidelines. Those which are associated with, or attached to, legal documents require that analyses comply with values quoted. This is obviously necessary because one cannot have a legal document with variable standards. However those which are published purely as guidance often have two values, one desirable and one a maximum acceptable value. Because the desirable value may be so much lower than the maximum acceptable value, caution has to be exercised in looking at these values quoted. In the remainder of this chapter there will be a discussion on the values in some of these published criteria and their relative importance in considering the quality of water supplies. Mandatory values must necessarily be complied with, but some other values may not be so pertinent to the United Kingdom situation. In the discussion, references will be made to the values in the major criteria such as those quoted already and an attempt will be made to discuss those where differences are apparent.