MICROBIOLOGICAL QUALITY CONTROL IN THE PROVISION OF SAFE DRINKING WATER

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ABSTRACT

The legislation from the European Commission and various other guidelines are discussed in the context of microbiological standards for drinking water. Difficulties in applying these standards are identified and reference is given to the quality control procedures adopted by Anglian Water. Pressures to achieve other drinking water standards, especially trihalomethanes, and the possible need to achieve higher microbiological quality objectives than those regulated currently, could lead to major changes in UK treatment practice.

KEYWORDS

Drinking water, safe, microbiological, quality, legislation, guidelines, treatment.

INTRODUCTION

For almost fifty years, since the Croydon typhoid epidemic (Holden, 1939), the British public has generally regarded the mains supply to be entirely safe to drink. This great trust is a tribute to the water industry over this time, but, in recent years doubts have increasingly been expressed. This new phenomenon results largely from the greater public awareness generated by the EC "drinking water" directive (EC, 1980) and the often scurrilous activities of certain environmental lobbyists. What then, is "safe" drinking water?

The premise of this paper, which is confined to microbiological issues, is that "safe" means "assured wholesomeness". Wholesome supplies, the statutory obligation of water undertakings (Water Act, 1973), should be aesthetically acceptable and pose no risk to health. Assurance is gained by adequately demonstrating to the customer that the supply is wholesome, implying the need for adequate quality control, allied to sound design and operational practice.

This review outlines the legislation and guidelines that apply to the United Kingdom, examines the features of sound quality control, and with reference to other European practices, considers likely longer term strategies for improving water treatment and the management of water supply quality.

LEGISLATION AND GUIDELINES

Since its implementation in July 1985, the EC directive has specified mandatory limits for the quality of drinking water in the U.K. For microbiological parameters the following standards apply:
(i) Total coliforms should be absent from at least 95% of 100 ml samples;

(ii) Faecal coliforms (E. coli) should be absent from all 100 ml samples;

(iii) Pathogenic organisms should be absent — reference is made to salmonella, pathogenic staphylococci, faecal bacteriophages, and entero-viruses;

(iv) Parasites, algae and animalcules should be absent;

(v) Guide levels rather than maximum admissible concentrations are given for bacterial colony counts; these are 100 per ml (22°C, 3 days) and 10 per ml (37°C, 1/2 days) and have been ignored largely by Government.

In applying these standards, the directive specifies minimum sampling frequencies for coliform bacteria and colony counts. For supplies which do not require disinfection, 12 samples per year per 10,000 population are specified, but for supplies which require disinfection, twice this frequency is specified. As it is British practice to disinfect all municipal supplies (NWC, 1979) the higher sampling frequency is the more relevant and is similar to well established British guidelines (DoE/DHSS/PHLS, 1982). Government guidelines (DoE, 1984) for implementing the directive clearly state that the microbiological standards of the directive apply at the point of use (ie the consumers tap). Although not absolutely clear, it is generally considered that sampling from consumers' taps should be on a random basis within each designated water supply area.

Minimum sampling frequencies are not specified in the directive for pathogens and parasites, and are for the "National Competent Authority" to determine. Further guidance from Government on this issue is needed.

As a means of implementing the directive, Government advised (DoE, 1984) that "Report 71" (DoE/DHSS/PHLS, 1982) was recommended as good practical guidance for water undertakers but various difficulties have been experienced:

(i) ambiguity regarding the sampling of water towers and service reservoirs as opposed to consumers' taps for assessing the compliance of distributed waters;

(ii) difficulty with the classification of a supply as "unsatisfactory" if a single sample in a year contained even one E. coli per 100 ml, or, if two consecutive samples contained coliforms;

(iii) uncertainty regarding appropriate frequencies for bacterial colony counts;

(iv) dispute (WRc, 1986) that the monitoring for coliforms precludes the need to monitor for pathogens;

(v) ambiguity in respect of fixed or random point monitoring for compliance assessment;

(vi) unclear guidance on what amounts to acceptable sampling frequencies for small supply areas.

In their guidance (DoE, 1984), Government advised that in assessing compliance with the directive's E. coli parameter (no. 58), samples containing E. coli by chance could be discounted; much debate has followed in an attempt to define "chance". The approach to classification of supply areas for compliance purposes is not only potentially volatile (one year a supply could be "unsatisfactory" and the next "excellent" and so on) but also, water undertakings are penalized for sampling more frequently; the greater the number of samples the greater the chance of obtaining an unsatisfactory sample, or consecutive unsatisfactory samples. The classification procedure of Report 71 was designed principally to heighten awareness of the possible significance of low level or intermittent coliform contamination (Barrow, 1987) and it is thus unfortunate that Government chose to use the procedure as the means of assessing formal compliance with the directive. World Health Organization guidelines (WHO, 1984) are broadly similar in respect of quality criteria and recommendations.

In recognition of the current difficulties, it is encouraging to note that the Government's Standing Committee of Analysts, in conjunction with the Water Authorities and Companies, are
reviewing Report 71. Additionally, it is anticipated that Government regulations pertaining to future "privatized" Water Authorities will more clearly define requirements for assessing compliance.

**QUALITY CONTROL**

Sound quality control procedures must include the pursuance of an appropriate pre-planned monitoring strategy, the results of which need to be periodically audited, both to determine performance and the efficacy of the procedures adopted. It cannot be overstated that water quality sampling has finite limitations in being able to accurately describe past or current events, and that good design and operational practice are an essential prerequisite to the continuous provision of wholesome drinking water.

Simple statistical theory can be used to define the risks, inherent in sampling, of poor water quality being undetected. This indicates (Warn, 1987) that even if 52 samples over a period of time are satisfactory, it is still possible for unsatisfactory conditions to pertain for 1% of that time period without being noticed; indeed, there is a 5% chance that unsatisfactory conditions could pertain for 6% of the time period and not be noticed. With 12 satisfactory samples, the possible unsatisfactory time increases to 3% with a 5% chance of it being 22%. Beyond the quantification of possible inadequacy in any sampling frequency, the statistical evaluation also highlights the relationship between specified minimum sampling frequency (eg as contained in the EC directive) and the water quality standard that, by default, is being applied. For example, despite the standard for E. coli requiring absolute absence, by taking 52 samples a year from a supply area the actual standard being applied is a 99th percentile. Further, if the Government's "chance E. coli" concept is interpreted as one failing sample per year per supply, then if 52 samples are taken, the standard in practice is equivalent to a 98th percentile.

In recognition of these risks and the guidelines contained in Report 71, Anglian Water monitor their 165 supply areas in the following manner:

(i) all groundwater sources in use are sampled 52 times a year (ie weekly);
(ii) all final treated waters from groundwater abstractions are sampled 52 times a year (ie weekly);
(iii) all final treated waters from direct river abstractions are sampled 365 times a year (ie daily);
(iv) all final treated waters from reservoir storage schemes are sampled at least 200 times a year;
(v) all 375 service reservoirs and water towers are each sampled 52 times a year (ie weekly);
(vi) all supply areas are sampled, largely on a random basis at consumers' taps, on the basis of one sample per month per 5,000 population, but with a minimum of 52 samples a year from each supply area.

Formal compliance with the EC directive of Anglian Water supplies is assessed annually, primarily on the basis of the data from customers' taps. The main purpose of monitoring sourceworks, service reservoirs and water towers is to determine operational performance but the data are also used in a supplementary manner for confirming that compliance has been achieved. The Quality Objectives adopted are the 95th percentile for total coliforms and the 98th percentile for E. coli but these are supported by a mandatory Code of Practice which requires that all failing samples are investigated and immediate remedial action is taken if necessary.

To ensure that compliance with the coliforms and E. coli parameters of the directive and adequate sampling frequencies are being maintained, quarterly audit is carried out on a rolling, annual, retrospective basis, the summary results of which are reported to Senior Management. These audit procedures are reported more fully elsewhere (Hayes et al, 1985). As Government have not promulgated standards for bacterial colony counts, these do not form part of the formal compliance assessment. Colony counts are carried out routinely, but only
to characterize the general sanitary condition of the water supply systems. Pathogens and parasites have, or will, be investigated on the basis of periodic survey, consistent with the use of coliforms and E. coli as surrogate indicators. So far, most attention has been directed to surveys for viruses, salmonellae and pathogenic staphylococci; at no time have these organisms been found in treated waters. Surveys for other organisms are planned.

The Anglian Water microbiological quality control programme extends to some 60,000 samples per year for the enumeration of coliforms, relating to the supplies to a population of 3.6 million. Consistently, the number of samples found to contain coliforms (one or more) has been less than 1% per annum for waters in distribution and at customer's taps. The great majority of first-time failing samples have been found satisfactory on resampling with satisfactory samples being obtained from neighbouring houses. In such cases the most likely explanation is "dirty" taps or artefacts of sampling and analysis. In recent years the only confirmed incidents of coliform contamination have been associated with low-level ingress at service reservoirs caused by leakage during heavy rainfall through faulty roof membranes. Rapid remedial action that included temporary closure, drain-down, cleaning and disinfection, has ensured that such incidents have been short-lived. Further, the regular scrutiny of microbiological quality at these points in the supply system has ensured that susceptible structures have been identified and these have either been permanently abandoned or repaired. The microbiological quality control programme, as described above, backed up by periodic operational inspection (eg, of service reservoirs), therefore provides for a high degree of reassurance to consumers that drinking waters supplied by Anglian Water are safe to drink. Reassurance is given through regular liaison with Chief Environmental Health Officers and Medical Officers of Environmental Health in two ways: regular reports and the immediate notification of any confirmed incidents of microbiological contamination.

The approaches to microbiological quality control that have been adopted by Anglian Water are considered to represent a sound interpretation of the legislation and guidelines. However, procedures and practices do differ across the United Kingdom and will, inevitably, continue to do so until such time as clearer and more precise National Guidelines or Regulations emerge. What is finally considered to be the "correct" approach remains to be seen.

PATHOGENIC AND PARASITIC ORGANISMS

The use of coliform bacteria as indicators of the possible presence of pathogens has enabled simple tests to be carried out on a frequent basis, facilitating rapid operational response if and when necessary. The very few incidents of waterborne disease in association with municipal supplies that have been reported since the Croydon outbreak (Galbraith et al, 1987) are testimony to the general success of this philosophy. However, there is increasing evidence that enteric-viruses can survive disinfection better than coliform bacteria (WRc, 1986). Further, even the definition of what amounts to a coliform bacterium (DoE/DHSS/PHLS, 1982) is being disputed. From a legislative standpoint, the requirement of the EC directive that pathogens must be absent implies the need for direct as well as indirect measurement. Also relevant is the unavailability of routine analytical methods for some of the viruses which could potentially be present in water supplies. Clearly, this aspect of microbiological quality control is still being developed. In view of the obvious relevance to public health, such development work must not be hindered (eg by lack of research funds!).

In the meantime, the approach adopted by Anglian Water has been to carry out periodic surveys for the pathogens most likely to be present, even though this likelihood is extremely small. So far none have been found.

Many cases of gastric illness are never reported, even to a General Practitioner. The true incidence of waterborne disease could therefore be much higher than indicated presently by Galbraith et al, 1987. Further and more extensive epidemiological study is warranted and should aim to determine:

(i) the public health significance of Aeromonads and the other non-coliform bacteria that are found commonly in water supplies;

(ii) the need for regular surveillance of viruses and other pathogens.
Despite the legislative requirements to perform a minimum number of bacterial colony counts, the current British philosophy relates primarily to the detection of sudden change as a means of identifying system ingress. This is valid generally for groundwaters but much more difficult to apply to supplies which are derived from organically enriched sources (e.g., lowland rivers containing treated sewage effluents and eutrophic reservoir waters). The latter often exhibit bacterial "aftergrowth" and it is by no means unusual to obtain random samples, on the same day from the same supply, that differ in their colony counts by several orders of magnitude, related to differences in water stagnation and residual disinfectant. The use of fixed points would be more appropriate for determining any sudden changes in colony counts but representativeness will always be difficult to achieve, particularly in large and complex water distribution networks. The guidance contained in Report 71 that bacterial colony counts are not of sanitary significance, and the finite availability of resources for quality control, have tended to result in only a limited effort being made to characterise the range of heterotrophic bacteria that are present in many UK supplies.

The low priority given to bacterial colony counts is, however, under review by the Government's Standing Committee of Analysts. Recent epidemiological evidence from Australia (Burke et al., 1984) expresses concern over the possible link between toxin producing strains of *Aeromonas* species and outbreaks of gastrointestinal disease. Recognizing this possibility, water undertakings in the Netherlands have adopted (Hulsman, 1987) tentative guidelines for *Aeromonas* spp as follows:

(i) Final treated water: ≤ 20/100 ml as a 90th percentile within one month;
(ii) Distributed water: ≤ 200/100 ml as a 90th percentile within one month;
(iii) In cases where 1000/100 ml is exceeded, Official bodies have to be informed and immediate action is taken.

Other heterotrophic bacteria (e.g., *Pseudomonas aeruginosa*) are also considered undesirable (DoE/DHSS/PHLS, 1982). It is therefore a distinct possibility that higher priority will in the future be given to the enumeration of these heterotrophic bacteria. If so, it may also be appropriate to review the method by which routine colony counts are obtained. Recent work in Anglian Water (Gibbs and Hayes, 1987) indicates that, on average, colony counts at 22°C are some 500 times greater if R2A medium is used with the spread-plate technique and incubation for 7 days, compared to the current Standard Method (DoE/DHSS/PHLS, 1982), that is: yeast extract agar, pour-plate technique and incubation for 3 days.

Other issues, that are generally considered to be outside the scope of supplying wholesome drinking water for domestic use, include microbial deterioration within industrial processes, institutional plumbing systems (especially hospitals) and drink vending machines. It is important that approved materials are used (e.g., washers), that have been tested with respect to their capability of supporting microbial growth, and that plumbing systems are designed and maintained properly.

In pursuing a wide range of quality objectives (there are 62 parameters in the EC directive) the achievement of microbiological quality standards is universally recognized as paramount. However, pressures from Government (DoE, 1987) to achieve other quality standards (particularly trihalomethanes and nitrite) may lead to extensive changes to current British practice, especially in the treatment of lowland, surface derived waters. It is worth noting here that concerns over the possible health effects of mutagenic compounds, formed during chlorination of organically enriched waters, has already led to major treatment changes in some of the water supplies of the Netherlands, e.g., the cessation of final water chlorination to supplies for Amsterdam (Schellart, 1987).

British guidelines for disinfection (NWC, 1979), which are also under review by the Water Industry, are essentially philosophical. These require all municipal supplies to be disinfected and for a suitable disinfectant residual to be maintained throughout distribution. Regarding the latter, the objectives are generally held to be:
(i) to provide protection in the event of ingress – however, would the typically low residuals carried be effective?

(ii) to avoid microbial deterioration within the distribution network – however, this is often not achieved (as judged by high colony counts) with organically enriched waters;

(iii) to provide a rapid indication of the ingress of polluting matter via a sudden change in disinfectant residual – to be valid, many continuous residual monitors would be required.

Additionally, the extent of disinfectant residual carried is constrained by palatability, chlorinous tastes being a common cause of customer complaint. In this context, it is also worth noting that most groundwater supplies in the Netherlands and West Germany are not disinfected so as to avoid adverse customer reaction, whilst in France, much effort has been directed towards the minimizing of chlorinous tastes (Levi and Jestin, 1987).

The upper concentration of residual disinfectant therefore depends on the local tolerance of consumers and perhaps the skill of the Public Relations Department! As for the lower acceptable concentration, this needs to be determined for the objectives cited, given that they are in fact valid. The specification of effective residuals is needed for all disinfectant types employed, notably free and combined chlorine. The only guidelines presently available in the UK emanate from the World Health Organization (WHO, 1984); these advise that when chlorination is practiced, a free chlorine residual of 0.2 to 0.5 mg/l should be maintained throughout distribution. In practice, this may not be feasible without adverse customer reaction to taste, especially in large distribution networks where attenuation of free chlorine may require far higher residuals to be maintained at or nearer to the sourceworks.

Compliance with standards for trihalomethanes further constrains the scope for employing chlorine as a disinfectant and for this reason many European water treatment plants use ozone. There is much disagreement on what the standard should be, ranging from 25µg/l in West Germany to 300µg/l in Canada. Even within the UK, whilst a standard of 100µg/l has been promulgated for England, Wales and Northern Ireland, 200µg/l applies to Scotland; these UK standards only relate to chlorine-containing compounds and ignore bromoform.

Compliance with the nitrite standard of the EC directive may also constrain the options for maintaining effective disinfection. Even though the standard of 0.1 mg/l (NO₂⁻) is generally considered to be unsound and overly stringent, there are still pressures on UK undertakings to achieve compliance. Nitrite has been observed to form within distribution systems receiving chloraminated water; in some cases, tighter control over ammoniation of final water has been successful in reducing nitrite concentrations but not in others. The use of the more stable chloramine residuals for reducing the extent of bacterial deterioration within distribution may therefore, in some cases, no longer be feasible.

Chlorine dioxide is used as a final disinfectant for some European waters but experience in Anglian Water, treating organically enriched reservoir waters, indicates that rapid reduction to chlorite occurs; not only is chlorite of little biocidal value but toxicological concerns have been expressed. For this reason, Government advice (DoE, 1985) limits the permitted chlorine dioxide dose to 0.5 mg/l (ClO₂⁻) unless treatment processes are available to reduce the residual of chlorite/chlorate/chlorine dioxide to the same concentration (DoE, 1986).

Many of the constraints described are exacerbated by the organic content of the water. This has been recognized, particularly in West Germany and the Netherlands, where biological treatment stages are employed specifically to reduce the assimilable organic carbon (AOC) content, the processes used most commonly being slow-sand filtration and biologically active, granular activated carbon. In the UK, physico-chemical plants have tended to be installed in preference to slow-sand filtration on cost grounds. A change in this trend can be envisaged (Hayes and Davis, 1986).

The advantages of AOC control are many:

(1) the potential for bacterial aftergrowth is diminished such that lower (if any) disinfectant residuals are needed throughout distribution;
(ii) the lower bacterial productivity reduces the likelihood of aquatic animal infestation which in the UK can require the dosing of pyrethrin or permethrin for remedial control;

(iii) the lower requirement for using disinfectants minimizes the extent of formation of mutagens and trihalomethanes;

(iv) the lower requirement for using disinfectants avoids adverse consumer reaction to palatability.

The only disadvantage is cost!

Should the Dutch and German philosophies on minimal use of disinfectants extend to the UK, or elsewhere, it will also focus attention on the audit of operational practices involved in water supply and put further emphasis on the protection of sources.

CONCLUSIONS

1. The microbiological quality control procedures operated in the UK have been generally successful, for the fifty years since the Croydon typhoid outbreak, in ensuring the provision of safe drinking water.

2. Despite this success, the procedures require clarification in some respects to avoid the possibility of variable interpretation.

3. It may be prudent to build upon the coliform indicator approach by periodic survey for pathogenic organisms.

4. Options for achieving microbiological quality standards have become increasingly constrained by the need to achieve other water quality standards.

5. These constraints may lead to costly extensions to current treatment in the UK, particularly for organically enriched waters.

6. The public health significance of Aeromonads and Pseudomonads needs to be clarified further. Improvements to the reporting of gastro-intestinal disease would help this clarification.

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