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# Tastes and odours in potable waters: perception versus reality

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Tastes and odours are amongst the few water quality standards immediately apparent to a consumer and, as a result, account for most consumer complaints about water quality. Although taste and odour problems can arise from a great many sources, from an operational point of view they are either "predictable" or "unpredictable". The former – which include problems related to actinomycete and algal growth – have a tendency to occur in certain types of water under certain combinations of conditions, whereas the latter – typically chemical spills – can occur anywhere. Long-term control is one option for predictable problems, although biomanipulation on a large scale has had little success. Detection and avoidance is a more practicable option for both predictable and unpredictable problems, particularly if the distribution network can be serviced from other sources. Where these are not feasible, then water treatment, typically using activated carbon, is possible. In general there is a reasonable understanding of what compounds cause taste and odour problems, and how to treat these. An efficient taste and odour control programme therefore relies ultimately on good management of existing resources. However, a number of problems lie outside the remit of water supply companies and will require more fundamental regulation of activities in the catchment.

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## Introduction: perceptions

The human chemical senses (taste and smell), though modest compared with those of many animals, are still extremely sensitive (Schmidt 1981). Even a substance as apparently simple and ubiquitous as drinking water provokes a myriad of sensations. Whilst pure water is both odourless and tasteless, characteristic tastes and odours are imparted by many naturally-present compounds, as well as by substances added deliberately (e.g. chlorine) or not (e.g. industrial pollutants) to the water. Adverse sensory reactions help animals to avoid potentially toxic foods and well-developed chemical senses impart clear selective advantages to organisms under many conditions. It is not surprising, then, that offensive odours and tastes account for most consumer complaints about water quality in some areas (Gray 1994).

In one long-term study, 44.5% of complaints about tap water in London concerned taste and odour (Windle Taylor 1965). Taste and odour are amongst the few water quality standards immediately apparent to a consumer and it has been shown (Manwaring *et al.* 1986) to be a strong motive for the purchase of bottled water. However, in another study in the UK (quoted in Gray 1994), the most commonly-quoted reason why water was deemed to have an unacceptable taste was due to chlorine, added to the water as a disinfectant. On the other hand, a slight chlorine odour is accepted as a sign that the water is safe to drink, and decreased levels of chlorination have led to outbreaks of diarrhoeal diseases. Also high on the list of reasons for not drinking tap water was a "metallic" taste, which might derive from household plumbing, rather than the water supply, treatment or distribution.

Although a great many odours and tastes associated with water have been isolated and characterised, routine chemical analysis remains difficult and expensive due to the range of possible causative agents at any one time. Routine testing is therefore performed by panels of individuals who are asked to describe any taste or odour present in a sample (see below). This in turn is complicated by the fact that compounds differ greatly in their pungency. In a recent incident, an accidental discharge of 2-ethyl-5,5-dimethyl-1,3-dioxene (2-EDD) from a factory in Wem, Shropshire, was still detectable 115 km downstream and the drinking water of 60,000 households was affected. 2-EDD can be tasted at a concentration of 0.01 g l<sup>-1</sup> although there was no threat to human health in this particular episode. It is pertinent to note that in his ruling the judge commented that although the water company was not responsible for the spillage itself, they had taken insufficient precautions at their water treatment works.

In 1984, two million households in North Wales and North-West England were affected by a spillage of phenolic material into the River Dee from an industrial site (Rushbrooke & Beaumont 1986), resulting in taste and odour problems arising from production of chlorophenols during water treatment. A similar spillage of phenol into the River Tyne caused chlorophenol taste and odour problems in households throughout North-East England, due to distribution of the water to various waterworks via the Tyne-Wear-Tees Transfer Scheme. Pollution episodes of this type are often not detected until they reach the consumer, by which time a large part of the distribution network may be contaminated.

It is, however, important to keep these incidents in perspective. An internal study by Northumbrian Water pointed out that there were no health risks associated with the spillage into the Tyne and the consumer, though aware of an off-putting taste and odour, is exposed to far higher concentrations of these compounds through gargling with pharmaceutical TCP preparations. Table 1 lists the proportions of analyses for taste and odour *per se*, submitted to the Drinking Water Inspectorate by water undertakings in 1994. More than 99.9% of the results for determinations of odour and 99.7% of those for taste were acceptable, although it is necessary to point out, when evaluating these data, that a single contravention may affect a large number of households. In most instances where there was a breach of standards, the water company concerned gave written undertakings to the Secretary of State that work to deal with breaches of compliance would be carried out, and in only six instances (all for taste) was it necessary for the Drinking Water Inspectorate to consider enforcement action. These data continue an overall downward trend in the number of occasions on which breaches of taste and odour quality thresholds have led to the consideration of enforcement action by the Drinking Water Inspectorate (Fig. 1). The overall reduction in such instances (for all determinands) between 1990 and 1994 was 76% and part of the improvement in taste and odour statistics will be side-effects of improvements in the treatment of other parameters. Yet the taste and odour is very much the "shop window" for a water company's product and it is in nobody's interest for these problems to persist.

Table 1. *Contraventions of acceptable taste and odour thresholds in fresh waters in England and Wales during 1994.*

Data from Drinking Water Inspectorate (1995).

Items	Odour	Taste
Total number of determinations	23017	23042
Number contravening prescribed value	19	51
	(0.08%)	(0.22%)
Contraventions covered by undertakings	0	9
Enforcement action considered	0	6

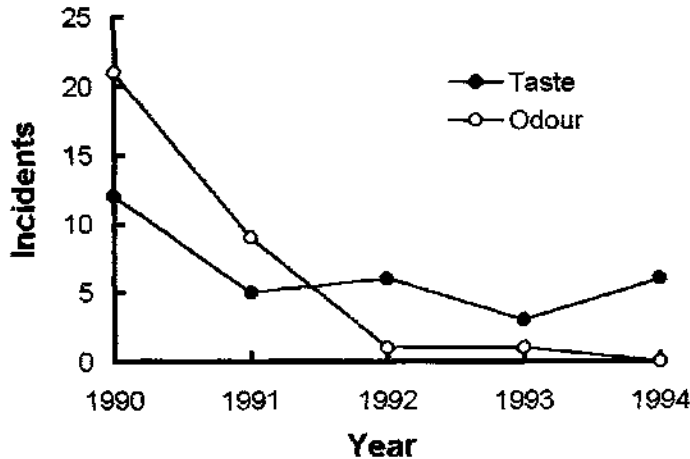


Figure 1. Enforcement actions in respect to breaches of Regulation 3(3) relating to water quality in water supply zones between 1990 and 1994. (Data from Drinking Water Inspectorate 1995).

It should be clear from this that the subject of tastes and odours crosses boundaries between “quantitative” and “qualitative” methods of analysis and between “objective” and “subjective”. Whilst most taste and odour problems are probably transient and/or innocuous, they can have a large effect on the public’s perception of its drinking water which can associate off-flavours in its water with media-reported stories of poor quality water (McGuire 1994).

#### Monitoring the taste and odour of potable water

Taste panels are still preferred over chemical methods for most routine purposes and provide the framework for the taste and odour requirements of potable water specified in European Community Directive 80/778 (Drinking Water Quality). The measure used in the EC Directive is the Threshold Number. The Threshold Odour Number (TON) is calculated as follows:

$$\text{TON} = (A+B)/A$$

where A is the volume of the original sample and B is the volume of diluent that must be added to the sample to give the least-perceptible taste. A+B is therefore the total volume of the sample after dilution. The Threshold Flavour Number (TFN) is calculated in a similar way to indicate taste. Both tests are conducted by panels of 3 to 20 (commonly 8) trained testers working with water at a temperature of 25°C and with specially prepared reference water, free from any taste or odour, as the diluent. For both taste and odour, the TFN specified by the Directive must be < 3. In the UK, panellists have to compare two samples at a time and continue until they can no longer perceive a difference between two samples. The geometric mean of the panellist’s threshold numbers is then used as the TFN for that sample (Standing Committee of Analysts 1995). This type of test is widely used throughout Europe and there is movement now towards a European standard (CEN) along these lines (Rigal 1995).

Threshold numbers describe the intensity of taste or odour in a sample. A second type of test, known as “flavour profile analysis”, is used to describe the taste and odour characteristics of a sample. Panellists attribute to a sample “descriptors” (single, identifiable characteristics perceived whilst tasting or smelling the sample), each with its intensity. If more than half of the panel use the same descriptor, then the intensity is calculated as the average of the individual intensities. If less than half use a descriptor, then it is added to the panel result as an “other note”. Some common descriptors, and their common causes, are listed in Table 2.

Taste panels, however, are likely to miss intermittent events such as the 2-EDD and trichlorophenol incidents described above. For this reason, tastes and odours are usually monitored by staff at water treatment works on an hourly basis. Typically, this involves a "smell bell" in which warmed water is sprayed onto the internal surface of a bell jar to concentrate any odour present.

Table 2. *Some common descriptors of odours associated with drinking water, with possible causes.*

Compiled from various published sources.

Class	Descriptor	Possible causes
Aromatic (spicy)	Camphor, cloves, lavender, lemon, cucumber	Moderate quantities of algae (especially Chrysophyta)
Balsamic (flowery)	Geranium, violet, vanilla, nasturtium	Moderate quantities of algae (especially Bacillariophyta)
Chemical	Chlorinous, hydrocarbon, medicinal, sulphuretted	Industrial wastes, water treatment processes
Disagreeable	Fishy, pig-pen, septic	Large quantities of algae (most divisions)
Earthy	Damp earth, peat	Actinomycetes
Grassy	Crushed grass	Moderate quantities of algae (Cyanobacteria, Chlorophyta, Bacillariophyta)
Musty	Mouldy	Actinomycetes, large quantities of some algae (especially Cyanobacteria)
Vegetable	Root vegetables	Algae

Table 3. *Causes of some taste and odour problems in drinking water.*

Compiled from various sources.

Taste/odour	Cause	Source Supply	Treatment	Distribution	Plumbing
Musty/earthy	Actinomycetes	●	●	●	●
	Cyanobacteria	●	—	—	—
Piggy/septic	Cyanobacteria and other algae	●	●	—	—
Grassy/fishy	Algae	●	●	—	—
Phenolic	Natural decay of organic material (or industrial pollution)	●	●	—	—
Rotten eggs	Iron and sulphur bacteria	—	—	●	●
Metallic	Principally iron, manganese, copper, zinc	—	●	●	●
Salty	Principally sodium chloride	●	—	—	—
Chlorine	Chlorination	—	●	—	—
Other chemical	Industrial wastes	●	—	—	—

### Sources of taste and odour problems

As almost any chemical – "natural" or "artificial" – that comes into contact with water can impart a taste or odour, an exhaustive review is impossible. Instead an "operational" classification of the source of taste and odour problems (over and above those imparted by bedrock geology) is adopted in this contribution. From the point of view of the manager of a water treatment works, taste and odour problems are either predictable or unpredictable.

Within the category of "predictable" problems we will concentrate on a variety of sources, mainly biological in origin, that have a tendency to occur in certain types of water at certain times of the year under certain combinations of environmental conditions. By predictable we

mean that the managers of water treatment works know that there is a chance of this type of problem occurring at least occasionally, even if they cannot predict exactly when. If the factors responsible for these problems are known then the possibility of long-term control can also be considered. These problems will represent the main focus of this review and we will attempt to answer, for those taste or odour problems that are most prevalent in the UK, the likelihood of effective control at source.

The unpredictable incidents would typically involve accidents at factories, such as described above, where all that can be realistically expected is for a water treatment works to have an early warning system and a contingency plan in place. Some measure of catchment protection is also possible, as discussed later.

An alternative way of classifying taste and odour problems is shown in Table 3, which attempts to break down the common problems depending upon where, in the whole process from abstraction to the tap, particular problems are located. Up to 60% of the quality problems in some areas are related to household problems, and the schematic nature of Table 3 loses some subtleties related to interactions between different components. The effect of water on copper piping in the household, for example, may depend amongst other things upon the degree of oxygenation of the water, in turn dependent upon the length of the distribution network and the length of time in which water stands in the water mains before use. Similarly, phenols resulting from the natural decay of organic matter or industrial pollution react with chlorine to produce a strong medicinal ("TCP") smell (Gray 1994). The Water Research Centre has prepared a helpful algorithm (Fig. 2) to aid in isolating exactly where in the treatment and distribution process the problems occur. Many problems can be handled by manipulations to the existing treatment and distribution network. Thus problems associated with "metallic" tastes (exacerbated in areas where the pH is low) may be solved simply in a number of ways, for example by replacing or renovating old iron mains, raising the pH, or adding calcium phosphate ("calgon") to stabilise the iron deposits in the mains. Where the problem is with the water supply, however, control may be much more difficult and, indeed, may fall outside the competence of the water company altogether. These circumstances are considered in some depth below.

#### **Problems associated with the raw water**

These are, overwhelmingly, of biological origin (except for areas reliant on groundwater where a combination of local geology and over-abstraction can lead to high salt concentrations). Problems of biological origin will depend upon a combination of ecological conditions (spatial and temporal) that favour the causative organisms. This means that the "problem" may persist for only a few weeks of the year, making it, perhaps, difficult to justify expensive capital investment in treatment processes.

The most common complaint is of earthy and musty tastes and odours, associated with the chemicals geosmin and 2-methylisoborneol (2-MIB). These are both tertiary alcohols whose structure makes them resistant to oxidation. They are produced primarily by actinomycetes (a group of fungal-like bacteria) (Wood *et al.* 1983) but also by cyanobacteria (blue-green algae) (Kenefick *et al.* 1992; Peterson *et al.* 1995). There is also evidence of interactions between actinomycetes and cyanobacteria, with the former using the latter as a carbon source and thereby enhancing production of 2-MIB (Sugiura *et al.* 1994). In addition, cyanobacteria also produce a compound called dimethylsulphide, the odour of which has been described as "grassy" at low concentrations, but when present at high concentrations is distinctly "septic".

The precise role of odour-producing actinomycetes in freshwater ecosystems is a matter of some debate. Whilst some species of actinomycetes are undoubtedly "aquatic" (Willoughby

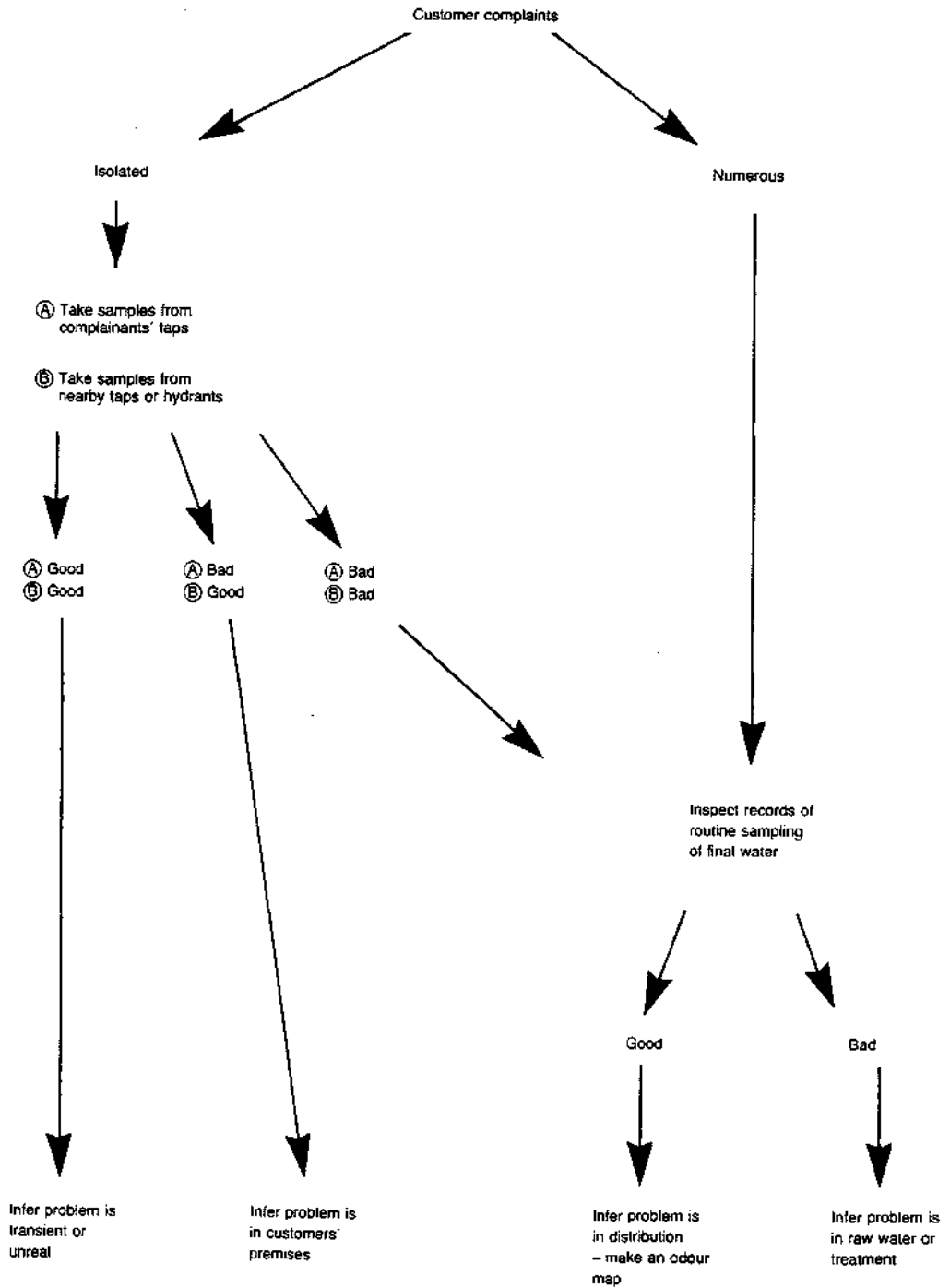


Figure 2. A schematic diagram illustrating how to investigate an odour problem. (Reproduced from Evins *et al.* 1990, with permission from the Water Research Centre).

1976; Cross 1981), many are soil species washed in to lakes and rivers. In the North Saskatchewan River in Canada, for example, numbers of actinomycetes increased rapidly at the onset of spring runoff as snow and ice melted (Jensen *et al.* 1994). Nonetheless, many species are undoubtedly able to grow in water under the right environmental conditions (Wood *et al.* 1983). These include high nutrient levels and the presence of plant debris, conditions easily satisfied in many lowland rivers in the UK. It is the plants and exposed mud at the margins of rivers and reservoirs that provide the best habitats for actinomycetes. Cold, anaerobic muds are a much less favourable habitat (Cross 1981) and for these reasons, shallow reservoirs are more likely to have actinomycete-related taste or odour problems than deep ones.

A valuable case study linked odour problems in two Oklahoma reservoirs to actinomycetes growing within filaments of *Cladophora* growing at the margins. The odour problem was most pronounced in winter when the alga decayed, releasing the actinomycete by-products into the water (Silvey & Roach 1953). There is anecdotal evidence of a great increase in the amount of *Cladophora* in lowland rivers in the UK over the last twenty years. We do not have any comparative figures for trends in odour-related problems.

The second major group of taste and odour-producing organisms in fresh water are cyanobacteria or "blue-green algae", large growths of which are usually confined to lowland reservoirs in the UK. The possession of gas vacuoles (which permit buoyancy regulation and therefore allow populations to maintain themselves at an optimum depth for photosynthesis), plus an ability to "fix" atmospheric nitrogen (which allows cyanobacteria to thrive under eutrophic conditions when the N/P ratio is low and other phytoplankton groups are N-limited) combine to allow the cyanobacteria to dominate phytoplankton in eutrophic lakes and reservoirs in summer when the water column is stratified and relatively stable.

There is a large literature on off-flavours produced by cyanobacteria from warmer parts of the world, such as the southern states of the USA (Vanderploeg *et al.* 1992), Australia (Bowmer *et al.* 1992) and South Africa (Wnorowski & Scott 1992), but less so from temperate regions. Increased geosmin concentration is a result of increased algal biomass rather than enhanced geosmin production by algae (Wnorowski 1992) and so, it follows, containing the spread of taste and odour problems associated with cyanobacterial origin will involve addressing the factors which allow cyanobacteria to proliferate in the first place. To some extent the recent focus on cyanobacterial toxins (Codd *et al.* 1995) may, as a by-product, help to control taste and odour problems, although there is no relationship between the presence of microcystin LR (a common cyanobacterial toxin) and the presence of odour compounds such as geosmin (Kenefick *et al.* 1992).

A number of other algal groups, including the Chlorophyta (green algae), Bacillariophyta (diatoms) and Chrysophyta (golden-brown alga) are also frequently associated with taste and odour problems (Table 4).

Table 4. Algal groups responsible for taste and odour episodes in North America.

Data from Barnett (1984).

Algal group	Frequency of responses (%)	Genera most commonly implicated
Cyanobacteria	46	<i>Anabaena</i> > <i>Aphanizomenon</i> > <i>Oscillatoria</i> > <i>Anacystis</i>
Bacillariophyta	21	<i>Asterionella</i> > <i>Synedra</i> > <i>Cyclotella</i> > <i>Tabellaria</i>
Chlorophyta	20	<i>Spirogyra</i> > <i>Scenedesmus</i> > <i>Pediastrum</i> > <i>Staurastrum</i>
Flagellates	14	<i>Dinobryon</i> > <i>Symura</i> > <i>Ceratium</i> > <i>Euglena</i>



### Control of taste and odour problems

Control of taste and odour problems in raw water can be effected at one of three stages considered below. The final strategy adopted for a particular treatment works will include components of all three stages and will probably be part of a wider action plan that will encompass control of other types of pollution as well.

#### *Catchment control of taste and odour*

Catchment control represents an ideal state in so far as likely problems are foreseen and prevented. This may reduce the incidence of "predictable" problems, while risk minimization strategies can reduce the probability of water pollution arising from random chemical spillages.

Interest in catchment control of nutrients in the UK is increasing for a number of reasons, including the increased attention on toxic cyanobacteria (see above) and the requirements of the European Community Directive 91/271 (Urban Wastewater Treatment). However, there are few examples of effective nutrient control, especially where water is abstracted from nutrient-rich lowland rivers and put into pump storage reservoirs such as Grafham and Rutland in East Anglia. Experiments have been tried with nutrient stripping, both at sewage works discharging upstream of the abstraction point and at the intake itself, but it now seems to be accepted that these processes are not effective under all circumstances.

Strategies for minimising the risk of accidental pollutions from chemical spillages include avoiding storing potential contaminants alongside watercourses, the use of properly bunded or contained storage areas, and the development of firefighting procedures that avoid the exacerbation of the problem by washing material off the site. The Water Resources Act 1991 (Section 93) allowed the National Rivers Authority (now the Environment Agency) to request the Government to establish Water Protection Zones (WPZ), within which such storage would be closely regulated. To date, the only proposed WPZ is for the River Dee catchment, mentioned earlier (NRA 1993).

It should also be noted that phenolic pollution incidents may also arise from spillages of agricultural slurries, particularly from dairy farms, and recently control has been improved by implementation of the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations S.I.1991:324.

#### *Detection and avoidance of taste and odour*

Detection and avoidance is a more practicable option in which water treatment works have on-line monitoring programmes, along with contingency plans, so that the intakes can be closed if an incident is suspected, and the distribution network is serviced by alternative sources. This is an option for both "predictable" and "unpredictable" problems, but may not be practicable in all regions if there is no alternative that can be rapidly switched on-line. It is, however, not unique to taste and odour problems, as the same contingency plans will operate for all pollution episodes likely to be encountered at a water treatment works.

A key component is the provision of alternative sources in case intakes have to be closed. Bankside storage reservoirs can act as "buffers" although, unless managed carefully, they too can develop cyanobacterial blooms. Bankside storage may also have other benefits: high rates of denitrification, for example, may reduce high ammonia concentrations.

In stratified lakes, the facility for multiple drawoff enables water to be withdrawn from the hypolimnion when there is an algal bloom in the epilimnion. This can lead to high manganese and iron concentrations in the raw water, but this is easier to remedy in the water treatment process than problems caused by algae.

*Treatment of water to remove tastes and odours*

Treatment of the water to remove the problem is the final option and there is an extensive literature on the technologies available (e.g. Montiel 1983; McGuire & Gaston 1988). No attempt at an exhaustive review is attempted here; instead a few general points are made. In general, activated carbon seems to be the preferred method of removing taste and odour problems, whilst the efficiency of ozonation is now being questioned, due to toxic side-effects. Decisions about whether activated carbon would be installed on-line or as a batch process, and whether powdered or granulated forms are preferred, need to be made locally. Where problems arise very sporadically then a simple "batch" addition of powdered activated carbon to the raw water may be sufficient.

Where problems are caused by algae, care must be taken to ensure that treatment does not enhance taste and odour problems by causing cells to lyse, thus releasing the metabolites responsible for the problem in the first place.

**Conclusions**

Three general points emerge from the preceding discussion.

- (1) Taste and odour problems cannot be considered in isolation from other factors which affect a potable water supply.
- (2) There is a reasonable understanding of what compounds cause taste and odour problems and of how best to monitor and treat these. Effective taste and odour control programmes (under most circumstances) are therefore largely management problems, rather than technical or scientific ones. If potential problems are anticipated and monitored correctly then most should be either avoided or controlled at the treatment works. The exceptions are problems arising within the distribution network.
- (3) A number of problems, however, remain out of the control of the water supply company. These include problems deriving from high nutrient concentrations or accidental pollutions within supply catchments.

Most of the problems with drinking water that are highlighted by the media cannot be detected by consumers. Tastes and odours, along with colour and turbidity, are the only yardsticks that most consumers have by which to judge the quality of their drinking water. Although most tastes and odour problems are not in themselves toxic, most consumers will believe that if their water smells and tastes "bad", then it is probably not safe to drink. A quotation by an American environmental consultant puts tastes and odours into perspective: "Water utilities will be defeating their best efforts to provide safe drinking water if they meet (health and safety) regulations but do not provide water that is free of taste and odour problems" (McGuire 1995). In the final analysis, perception is reality

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