5

Treatment variability

Maintaining reliable treatment performance is critical for minimizing microbial risk, because health effects associated with microbial contaminants tend to be due to short-term, single dose exposure rather than long-term exposure. However, drinking-water treatment is a dynamic process and the treatment efficiency for removal or inactivation of microbial pathogens is variable. This is illustrated by an on-site survey of 100 water treatment plants across the USA, which found that the removal efficiency of particles greater than 2 μm ranged from 0.04 to 5.5 logs, with a median value of 2.8 logs (McTigue et al., 1998). The study also found significant variation in the removal efficiencies of *Cryptosporidium* oocysts and *Giardia* cysts, although the removal of these pathogens did not necessarily correlate directly with the removal of particles.

Some process variation is normal and expected; however, too much variability can result in treatment failures, leading to waterborne disease outbreaks. It is the objective of drinking-water standards, therefore, to keep process variability within acceptable limits.

Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by Mark W LeChevallier and Kwok-Keung Au. ISBN: 1 84339 069 8.
Published by IWA Publishing, London, UK.

This chapter looks at the possible effects of treatment process variability, how changes in one unit process can affect the efficiency of other processes, the dynamic nature of treatment processes, the effects of changes in raw water quality and the variation that can arise from process measurements.

5.1 EFFECTS OF PROCESS VARIABILITY

Treatment efficiency for removal of microbes may vary between treatment plants, between unit treatment processes and between microbes. The net result is that removal efficiency may some sometimes be low. Figure 5.1 shows hypothetical log removals of a microbe by the conventional water treatment processes of coagulation and clarification, filtration and disinfection, as a cumulative frequency distribution function. An average removal of, for example, 1 log by coagulation and clarification, 2 logs by filtration and 3 logs by disinfection would result in an average removal of 6 logs for the combined processes. However, because of the variability associated with each unit process, the removal efficiency may be as low as 3.4 logs for 10% of the time.

Although it may be possible to offset the reduced performance of removal processes (e.g. coagulation and clarification, and filtration) with increased disinfection, often the failure of one process affects the performance of other processes. This is because unit processes in water treatment plants are interrelated, as described below.

5.2 RELATIONSHIPS BETWEEN TREATMENT PROCESSES

The performance of a treatment unit can affect the efficiency of downstream treatment units. For example, the presence of suspended solids increases the resistance of most microbes to disinfection (LeChevallier, Evans & Seidler, 1981). Therefore, a failure in the removal efficiency of turbidity or particles by granular filtration processes can decrease the inactivation efficiency of disinfection processes. Similarly, clarification affects filter performance. Clarification removes suspended solids, thus reducing the solid loading to the filters and improving filter performance. If an incorrect dose of coagulant is used and floc is carried over from a sedimentation tank, head loss develops more rapidly, shortening the filter run.

A further example of how treatment processes are related is the effect of pre-oxidation on the removal of particles and microbes by granular filtration. By affecting the surface properties of particles and microbes, pre-oxidation can improve the performance of granular filters (Au et al., 2002). However, many water utilities are considering delaying or omitting the addition of oxidants such as chlorine and ozone before filtration, in an attempt to reduce the formation of disinfectant by-products. These strategies must be carefully considered because of possible adverse effects on filtration performance (Au & LeChevallier, 2000). Possible impacts (either positive or negative) on other unit processes must be evaluated when considering modification of any unit process to achieve a particular microbial goal.

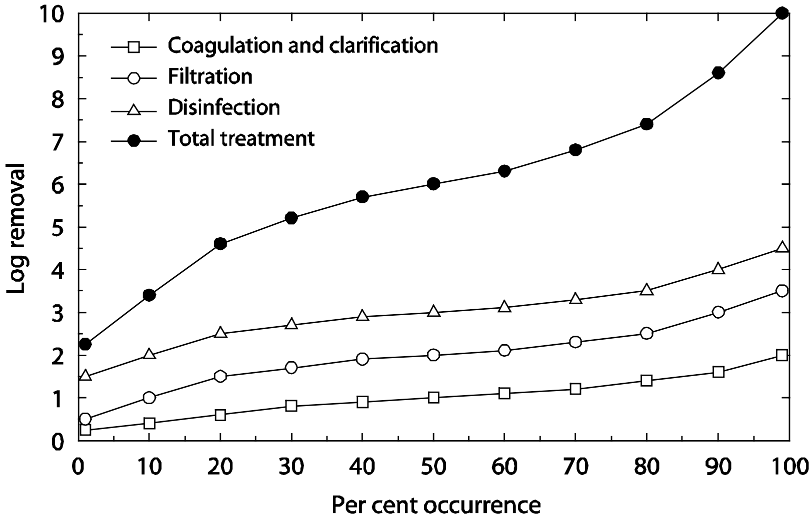

Figure 5.1 Hypothetical example of log removal as function of per cent occurrence.

5.3 DYNAMIC NATURE OF TREATMENT PROCESSES

Variation in the efficiency of water treatment processes can be due to the dynamic nature of the processes. For example, removal efficiency of granular media high-rate filtration varies throughout a filter run, which may last from a few hours to several days. As described in Chapter 2 (Section 2.5.1), after a filter is cleaned by backwashing, it performs poorly during the ripening period, before achieving a stable level of performance, which will eventually be followed by degradation and breakthrough of microbes at the end of the run. The effect of the variable performance of an individual filter on the final quality of the filtered water can be reduced by using multiple filters. This concept is similar to that of multiple barriers, where sufficient overlap in treatment systems ensures a reliable finished water quality.

5.4 EFFECTS OF CHANGES IN RAW WATER QUALITY

Changes in raw water quality can affect the efficiency of treatment processes. Depending on local and seasonal situations, each water treatment plant encounters different ranges of raw water quality. Data from 67 surface water treatment plants in the USA showed that the variation in particles greater than 3 μm in raw water followed a log-normal distribution pattern; particle concentrations ranged from 28/ml to 11×10^7/ml, with a geometric mean of 22 800/ml (Arora et al., 1998). Factors influencing raw water quality are discussed in Chapter 6 (Section 6.2). A change of any water quality parameter in the source water may affect apparent treatment efficiency, as discussed in Section 5.3. For example, in their study of 67 surface water treatment plants in the USA, Arora et al. (1998) found that the removal efficiency (based on the difference in particle concentrations between raw and filtered waters) increased with increasing particle concentration in raw water. For raw water particle concentrations from 10^3–25×10^3/ml, the median removal efficiency was 2.08 logs; whereas, when concentrations increased to 10^6–10^7/ml, the median removal efficiency increased to 3.2 logs. The greater removal efficiency at higher particle concentrations was due primarily to more efficient clarification. This is to be expected because removal of particles by clarification depends significantly on aggregation efficiency, which is a second-order process with respect to particle concentration (i.e. a higher particle concentration means that particles will collide more frequently and thus be more likely to aggregate).

5.5 VARIABILITY DUE TO PROCESS MEASUREMENTS

With respect to removal of microbes, treatment reliability relates to the expected variation in treatment performance. Monitoring of process performance must include assessment of variability. However, uncertainties in analytical measurements may make this process more complex, particularly when few analyses are performed (Frey et al., 1998). Direct measurements of treatment performance for microbial removal may be difficult due to the time it takes to perform the analysis and the low concentrations of microbes in raw waters. Surrogate measures such as turbidity, particle counts or total coliforms may be used, but these also have limitations (Nieminski & Bellamy, 2000).

These difficulties and limitations create uncertainties in estimating treatment performance, meaning that observed (apparent) treatment performance and variability may not reflect the actual (intrinsic) performance. For example, a treatment plant may show 2 logs of particle count removal, resulting in an effluent count of 10 particles/ml. If the source water particle count increases due to a storm event, so that the difference between the source water level and the treated count (which is still 10 particles/ml) is now 4 logs, without any change in treatment parameters, has treatment improved? Using the apparent measure of performance (i.e. particle counts), the conclusion would be that it has improved. However, the apparent improvement of the performance of the treatment process was influenced by changes in the source water; the intrinsic capability of the plant to provide 4 logs of microbial protection may have been present all along!

A study by McTigue et al. (1998) illustrates this point (Table 5.1). In pilot plant experiments, the level of *Cryptosporidium* was varied from 26 to 4610 oocysts/l. Monitoring of the plant effluent showed a consistent removal of approximately 4 logs. Turbidity and particle count data, which were limited because of relatively low levels in source water, showed an apparent removal of 1.0–1.6 logs. A plot of *Cryptosporidium* levels in raw water versus detection of oocyst in filtered effluent suggests that breakthrough occurs at a treatment plant performance level of approximately 4–5 logs (Figure 5.2).

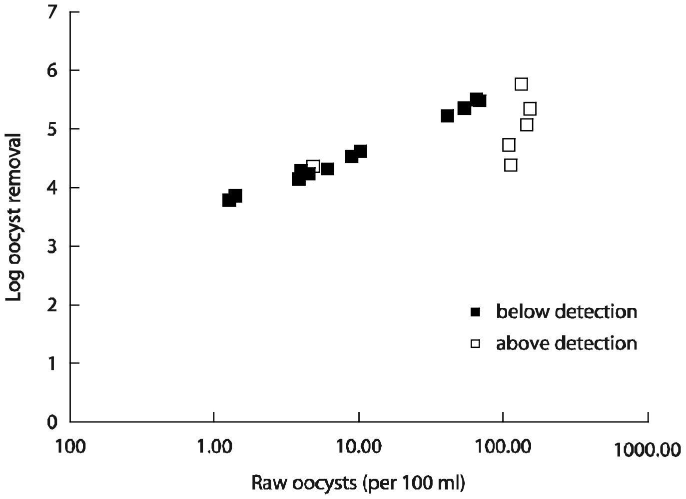

Figure 5.2 Evaluation of a pilot treatment plant performance for removal of *Cryptosporidium* oocysts. Data demonstrate performance of 4–5 log removal. Source: D Cornwell, personal communication (2001).

Table 5.1 Impact of source water concentration on apparent treatment performance (results of three trials)

Oocysts/l			Turbidity (NTU)			Particles > 3 µm/ml		
Raw	Effluent	Log removal	Raw	Effluent	Log removal	Raw	Effluent	Log removal
26	0.0017	4.2	2.5	0.07	1.6	7000	350	1.3
688	0.041	4.2	2.0	0.07	1.5	7700	530	1.2
4610	0.214	4.3	1.3	0.07	1.3	4700	480	1.0

NTU = nephelometric turbidity unit
Source: McTigue et al. (1998)