CHAPTER 5

MANAGING WATER AND AIR QUALITY

This chapter builds upon the background provided in chapters 2, 3 and 4. The primary water and air quality health challenges to be dealt with are, in order of priority, controlling clarity to minimize injury hazard, controlling water quality to prevent the transmission of infectious disease, and controlling potential hazards from disinfectant by-products. These challenges can be met through optimal matching of the following factors:

- treatment (to remove particulates, pollutants and microorganisms);
- disinfection (to destroy or remove infectious microorganisms so that the water cannot transmit disease-producing biological agents);
- pool hydraulics (to ensure optimal distribution of disinfectant throughout the pool); and
- addition of fresh water at frequent intervals (to dilute substances that cannot be removed from the water by treatment).

Controlling clarity, the most important water quality criterion, involves adequate water treatment, usually involving filtration and coagulation. The control of pathogens is typically achieved by a combination of recirculation of pool water through treatment (typically involving some form of filtration plus disinfection) and the application of a residual chemical disinfectant to inactivate microorganisms introduced to the pool itself by, for instance, bathers. Pools that cannot be treated or disinfected need special management. As not all infectious agents are killed by the most frequently used residual disinfectants, and as removal in treatment is slow, it is necessary to minimize accidental faecal releases (AFRs) and vomitus, and to respond effectively to them when they occur; and to minimize the introduction of shed organisms by pre-swim hygiene.

Microbial colonization of surfaces can be a problem and is generally controlled through cleaning and disinfection. The control of disinfectant by-products requires dilution, pre-swim showering, treatment and disinfection modification or optimization, and changing people's behaviour.

5.1 Pre-swim hygiene

In some countries — in Europe, for instance — it is quite routine (even compulsory) to shower before a swim. Showering will remove traces of sweat, urine, faecal matter, cosmetics, suntan oil and other potential water contaminants.

Where pre-swim showering is required, pool water is cleaner, easier to disinfect with smaller amounts of chemicals and thus more pleasant to swim in. Money is saved on chemicals (offset to some extent by the extra cost of heating shower water).

Pre-swim showers that are separate from post-swim showers and private (to encourage nude showering) are generally preferable. They should be on the route from changing rooms to pool. They can be continuous to encourage use. Pre-swim showers must run to waste. Showers must be provided with water of drinking water quality, as children and some adults may ingest the shower water.

The role of footbaths and showers in dealing with human papilloma virus (section 3.5.2) and other foot infections is under question. However, it is generally accepted that there must be some barrier between outdoor dirt and the pool in order to minimize the transfer of dirt into the pool. If there is no alternative, especially in an outdoor pool, a properly maintained footbath (or foot spray) should be installed.

Toilets should be provided where they can be conveniently used before entering the pool and after leaving the pool. All users should be encouraged to use the toilets before bathing to minimize urination in the pool and AFRs. Babies should be encouraged to empty their bladders before they swim.

5.2 Disinfection

Disinfection is a process whereby pathogenic microorganisms are removed or inactivated by chemical (e.g., chlorination) or physical (e.g., filtration, UV radiation) means such that they represent no significant risk of infection. Recirculating pool water is disinfected during the treatment process, and the entire water body is disinfected by application of a disinfectant residual, which inactivates agents added to the pool by bathers. Facilities that are difficult or impossible to disinfect (e.g., spa pools with thermal and medicinal waters) pose a special set of problems and generally require very high rates of water exchange to maintain water quality.

For disinfection to occur with any biocidal chemical, the oxidant demand of the water being treated must be satisfied and sufficient chemical must remain to effect disinfection.

5.2.1 Choosing a disinfectant

Issues to be considered in the choice of a disinfectant and application system include:

- safety (occupational health and safety are not covered here, except for occupational exposure to disinfectants and disinfectant by-products; see chapter 4);
- compatibility with the source water supply (matching the chemical characteristics of the disinfectant, such as its effect on pH, with the source water contributes to minimizing cost);
- type and size of pool (disinfectant may be more readily degraded or lost through evaporation in outdoor pools);
- bathing load (sweat and urine from bathers will increase disinfectant “demand”); and
- operation of the pool (i.e., supervision, management).

The choice of disinfectant used as part of swimming pool water treatment should ideally comply with the following criteria:

- effective, rapid, inactivation of pathogenic microorganisms (including, ideally, viruses, bacteria and protozoa);
- capacity for ongoing oxidation to assist control of contaminants during pool use;
- a wide margin between effective biocidal concentration and concentrations resulting in adverse effects on human health (adverse health effects of disinfectants are briefly reviewed in section 4.3.1);
- availability of a quick and easy determination of the disinfectant’s concentration in pool water (simple analytical test methods and equipment); and
- potential to measure the disinfectant’s concentration electrometrically to permit automatic control of disinfectant dosing and continuous recording of the values measured.

5.2.2 Characteristics of various disinfectants

1) Chlorine-based disinfectants

Chlorination is the most widely used pool water disinfection method, usually in the form of chlorine gas or sodium or calcium hypochlorite. Chlorine is inexpensive and relatively convenient to produce, store, transport and use.

When chlorine gas or hypochlorite is added to water, hypochlorous acid (HOCl) is formed. Hypochlorous acid dissociates in water into its constituents H^+ and OCl^- (hypochlorite ion), as follows:

$$HOCl \leftrightarrow H^+ + OCl^-$$

The degree of dissociation depends on pH and (much less) on temperature. Dissociation is poor at pH levels below 6. At pH levels of 6.5–8.5, a change occurs from undissociated hypochlorous acid to nearly complete dissociation. Hypochlorous acid is a much stronger disinfectant. This may be due to the fact that hypochlorous acid is electrically neutral and therefore capable of diffusing through the cell walls of microorganisms and reacting with proteins that are inaccessible to the charged OCl^- ion.

To achieve good disinfection of water with chlorine or a salt of hypochlorite, control of pH is, therefore, very important. At a pH of 8.0, for example, 21% of the free chlorine exists in the hypochlorous acid form (acting as a strong, fast, oxidizing disinfectant), and at a pH of 8.5, only 12% of that chlorine exists as hypochlorous acid. For this reason, the pH value should be kept relatively low and within defined limits. A pH value of swimming pool water between 6.5 and 7.6 is generally preferred (Deutsches Institut für Normung, 1997a), and chlorine is generally considered ineffective at pH 8 or above. Together, hypochlorous acid and OCl^- are referred to as free chlorine. The usual test for chlorine detects free chlorine and is an inadequate measure of disinfectant availability unless the pH value is also known.

2) Chlorinated isocyanurates

The chlorinated isocyanurate compounds are somewhat complex white crystalline compounds with a slight chlorine-type odour that provide free chlorine (HOCl) when dissolved in water. They are an indirect source of chlorine, via an organic reserve (cyanuric acid). This can be represented by the equation:

$$\underset{\text{chloroiso-cyanurates}}{Cl_xH_{3-x}Cy} + \underset{\text{water}}{H_2O} \leftrightarrow \underset{\text{cyanuric acid}}{H_3Cy} + \underset{\text{hypochlorous acid}}{HOCl}$$

x = 1 (mono-); 2 (di-); 3 (tri-)

The relative amounts of each compound are determined by the pH and free chlorine concentration. As the disinfectant (HOCl) is used up, more chlorine atoms are released from the chloroisocyanurates to form hypochlorous acid. This results in an enrichment of isocyanuric acid in the pool that cannot be removed by the water treatment process. Dilution with fresh water keeps the isocyanuric acid concentration at a satisfactory level.

The relationship between the chlorine residual and the level of cyanuric acid is critical and can be difficult to maintain. If it is lost because cyanuric acid levels become too high, unsatisfactory microbiological conditions can result. As a result, chlorinated isocyanurates are not suited to the variations in bathing loads usually found in large public pools. They do, however, have a place in the disinfection of small, lightly loaded public and semi-public pools and, in particular, private pools, especially in areas with hard water.

Chlorinated isocyanurates are particularly useful in outdoor swimming pools exposed to direct sunlight, where UV radiation rapidly degrades free chlorine. When used in association with chlorine, cyanuric acid has been shown to stabilize the chlorine residual, conferring a degree of resistance against the degrading effects of UV radiation (Gardiner, 1973). The reaction of cyanuric acid added to the water with free chlorine forms chlorinated isocyanurates. The stabilizing effect of cyanuric acid is the same at a given concentration whether it is derived from the acid itself in combination with the hypochlorous acid in the pool or whether it enters the pool in the form of a chlorinated isocyanurate compound.

Cyanuric acid in chlorinated water, whether introduced separately or present through the use of chlorinated isocyanurates, will reduce the amount of free chlorine. At low levels of cyanuric acid, there is very little effect; as the cyanuric acid level increases, however, the disinfecting and oxidizing properties of the free chlorine become progressively reduced. High levels of cyanuric acid cause a situation known as “chlorine lock” — when even very high levels of chlorine become totally locked with the cyanuric acid (stabilizer) and unavailable as disinfectant.

The cyanuric acid level must therefore be monitored and controlled relative to chlorine residual: if the former becomes too high, microbiological conditions may become unsatisfactory. Suggested targets for cyanuric acid levels range from 15 mg/litre (Grohmann & Carlson, 1977; Saunus, 1998) to 50–100 mg/litre (PWTAG, 1999). A simple photometric determination as cyanuric acid–melamine complex by turbidity measurement can be used for monitoring. For effective disinfection, the pH value must also be monitored, because the influence of pH on disinfection efficiency is the same as described for chlorine-based disinfectants.

Although hand-dosing chlorinated isocyanurates or using circulation feeders appears easier than other methods, dosing accuracy is likely to be compromised.

3) Bromine-based disinfectants

Elemental bromine is a heavy, dark brown, volatile liquid with fumes that are toxic and irritating to eyes and respiratory tract, and it is not suitable for swimming pool disinfection.

For pool sanitation, bromine compounds are available in two solid forms — a one-part system that is a compound of both bromine and chlorine each attached to a nitrogen atom of dimethylhydantoin (DMH) as organic support for the halogens, and a two-part system that uses a bromide salt dissolved in water and activated by addition of a separate oxidizer.

Bromochlorodimethylhydantoin (BCDMH) is an organic compound that oxidizes and disinfects with a free bromine residual, because it dissolves in water to release hypobromous acid (HOBr) and hypochlorous acid, which reacts with reduced bromides (Br^-) to form more hypobromous acid:

Br-(DMH)-Cl	+	2 H_2O	↔	HOBr	+	HOCl	+	H-(DMH)-H
Bromochloro-dimethyl-hydantoin		water		hypo-bromous-acid		hypo-chlorous-acid		dimethyl-hydantoin

$$\mathrm{HOBr} \xrightarrow[\textit{oxidation}]{\textit{disinfection}} \mathrm{Br^-}$$

$$\mathrm{HOCl + Br^- \longrightarrow HOBr + Cl^-}$$

It can, therefore, be used both for treatment (oxidation) and to provide a disinfectant residual. Like the chlorinated isocyanurates, failure to maintain the correct relationship between the disinfectant residual and the organic component can result in unsatisfactory microbiological conditions. The level of DMH in the water must be limited and should not exceed 200 mg/litre (PWTAG, 1999). There is no poolside test kit available, and the need to regularly monitor DMH by a qualified laboratory is a disadvantage of the use of BCDMH. On the other hand, BCDMH is relatively innocuous in storage, is easy to dose and often does not need pH correction. It is mostly available as tablets, cartridges or packets. BCDMH has a long shelf life and dissolves very slowly, so it may be used in floating and erosion-type feeders.

The two-part bromine system consists of bromide salt (sodium bromide) and an oxidizer (hypochlorite, ozone). The salt is added to the water, and then the oxidizer is added to activate the bromide into hypobromous acid:

$$\mathrm{Br^- + oxidizer \longrightarrow HOBr}$$

Disinfectant action returns hypobromous acid to bromide ions, which can again be reactivated.

Bromine combines with some water impurities to form combined bromine, including bromamines. However, combined bromine acts as a disinfectant and does not smell. Bromine does not oxidize ammonia and nitrogen compounds. Because of this, bromine cannot be used for shock treatment. Hypobromous acid reacts with sunlight and cannot be protected from the effects of UV light by cyanuric acid or other chemicals.

4) Ozone

Ozone can be viewed as the most powerful oxidizing and disinfecting agent that is available for pool and spa water treatment (Rice, 1995; Saunus, 1998). However, it is unsuitable for use as a residual disinfectant. This is because it readily vaporizes, leading to discomfort and adverse health effects (Locher, 1996), and because it decomposes relatively rapidly. Ozone is, therefore, most frequently used as a treatment step, followed by deozonation and addition of a residual disinfectant, such as chlorine or bromine.

The use of an ozonation system that is properly sized and integrated into the swimming pool treatment system (see, for example, Deutsches Institut für Normung, 1997b, 1999) will allow ozone to act as the primary oxidizer and disinfectant. All of the recirculating water is treated with sufficient amounts of ozone (between 0.8 and 1.5 g/m^3, depending on the water temperature) to satisfy the ozone demand of the water and attain a residual of dissolved ozone for several minutes. Under these conditions, ozone oxidizes many impurities (e.g., THM precursors) and microorganisms (disinfection), thereby reducing chlorine demand. Lower chlorine demand allows the pool operator to achieve final disinfection of the water with less free chlorine residual.

Excess ozone must be destroyed (forming oxygen and carbon dioxide) by an activated carbon filter, because this toxic, heavier-than-air gas could settle, to be breathed by pool/spa users and staff. It has been recommended that the ozone level in pool water should not exceed 0.05 mg/litre (Deutsches Institut für Normung, 1997b). Residual disinfectants would also be removed by the activated carbon filter and are, therefore, added after this.

Chloramines are oxidized by ozone into chloride and nitrate (Eichelsdörfer & Jandik, 1979, 1984), and precursors of disinfectant by-products are also destroyed, resulting in very low levels of THMs (<0.02 mg/litre) (Eichelsdörfer et al., 1981; Eichelsdörfer, 1987) and other chlorinated organics. The use of ozone in conjunction with chlorine (to ensure a disinfecting residual throughout the pool or spa) is considerably more expensive than that of chlorine alone.

Ozone can also be used in combination with bromine. In applying this system, about 15 mg/litre of bromide ion (as sodium bromide) is maintained in the recirculating water. During ozonation, the bromide ion is oxidized to free bromine (as described for bromine-based disinfectants). Residual disinfection in the pool/spa water is provided by free bromine. During disinfection, some bromide ion is formed, which is again oxidized by ozone to free bromine in recirculation.

Addition of excessive quantities of bromide ion to the water can result in more and more of the applied ozone producing more and more free bromine and less and less ozone being available to oxidize pool contaminants and kill microorganisms. Therefore, the concentration of bromide ion should be monitored and maintained at, for instance, 15–20 mg/litre at all times (Barlow, 1993).

An ozone system in combination with BCDMH is also in use. However, the practice is to add only small amounts of ozone to this system to oxidize only the bromide resulting from the spent hypobromous acid back to hypobromous acid. Therefore, this BCDMH/ozone combination only allows less BCDMH to be added and does not provide for ozone oxidation and disinfection (the most important steps) of the recycling pool or spa water.

5) Ultraviolet radiation

Like ozone, UV radiation is a plant-room treatment that purifies the circulating water, inactivating microorganisms and to a certain extent breaking down some pollutants (e.g., chloramines) by photo-oxidation. This decreases the chlorine demand of the purified water but does not leave a disinfectant residual in the pool water.

For UV to be most effective, the water must be pretreated to remove turbidity-causing particulate matter that prevents the penetration of the UV radiation or absorbs the UV energy (Saunus, 1998). Disadvantages of UV are the lack of a field test that readily establishes the efficiency of the process desirable for adequate water quality management and its inability to provide any residual disinfecting capacity to protect against recontamination (Parrotta & Bekdash, 1998).

6) Silver

The use of silver as a germicide is described as a result of its oligodynamic action on biological processes. Oligodynamics means simply “effect or power in small amounts.” An explanation of the oligodynamic activity of silver and its limitation as a disinfectant was reported by Grohmann (1991).

The demand for fast biocidal action — to ensure that an infection of swimmers by transmission of bacteria and viruses via pool water does not occur even when the pool is used in rapid succession by large numbers of bathers — rules out the use of silver or other heavy metals for pool water disinfection, because a long exposure period (several hours) is required for these substances to show a biocidal effect (Shapiro & Hale, 1937; Saunus, 1998). A quick, sensitive, analytical field procedure for measuring low concentrations of silver is not available.

7) Algicides

Algicides are used to control algal growths, especially in outdoor pools. Algal growth is possible only if the nutrients phosphate, nitrogen and potassium are present in the pool water. Phosphate can be removed from the pool water by an optimal flocculation and filtration step during water treatment. Consequently, such growths are best controlled by ensuring effective flocculation/filtration, disinfection and good hydraulic design. In such properly managed pools, the use of algicidal chemicals for the control of algae is not necessary (Gansloser et al., 1999). If problems persist, however, then proprietary algicides can be used. Quaternary ammonium and polyoximino compounds and copper salts can be used, but any based on mercury — a toxic and cumulative heavy metal — should not be added to swimming pools (PWTAG, 1999). All should be used in strict accordance with the suppliers' instructions and should be intended for swimming pool use.

5.2.3 Disinfectant by-products

The production of disinfectant by-products (see chapter 4) can be controlled to a significant extent by minimizing the introduction of precursors though good hygienic practices (e.g., pre-swim showering) and maximizing their removal by well-managed pool water treatment. It is inevitable, however, that some volatile disinfectant by-products, such as chloroform and trichloramine, will be produced in the pool water and escape into the air. This hazard can be managed to some extent through good ventilation (section 4.5).

5.2.4 Disinfectant dosing

The method of introducing disinfectants to the pool water influences their effectiveness. Individual disinfectants can have their own specific dosing requirements, but the following principles apply to all:

- Automatic dosing is preferable: electronic sensors monitor pH and residual disinfectant levels continuously and adjust the dosing correspondingly to maintain correct levels. Regular verification of the system (including manual tests on pool water samples) and good management of it are important. Section 5.12.2 describes the monitoring procedures.
- Hand-dosing (i.e., putting chemicals directly into the pool) is rarely justified. Manual systems of dosing must be backed up by good management of operation and monitoring. It is important that the pool is empty of bathers until the chemical has dispersed.
- Trying to compensate for inadequacies in treatment by shock dosing is bad practice, because it can mask deficiencies in design or operation that may produce other problems and can generate extra unwelcome by-products (e.g., THMs, chloramines). If not enough chlorine is added, the combined chlorine (chloramines) problem is only made worse, and conjunctival irritation and obnoxious odours in the pool area are raised to very high levels. If too much chlorine is added, it may take days to drop to safe levels before bathing can be resumed.
- Dosing pumps should be designed to shut themselves off if the circulation system fails (although automatic dosing monitors should remain in operation) to ensure that chemical

dispersion is interrupted. If chemical dosing continues without water circulating, then high local concentrations of the dosed chemical will occur. On resumption of the circulation system, the high concentration will progress to the pool. If, for example, both hypochlorite and acid have been so dosed, the resultant mix containing chlorine gas may be dangerous to bathers.

- Residual disinfectants are generally dosed at the very end of the treatment process. The treatment methods of flocculation, filtration and ozonation serve to clarify the water, reduce the organic load (including precursors for the formation of disinfectant by-products) and greatly reduce the microbial count, so that the post-treatment disinfectant can be more effective and the amount of disinfectant that must be used can be minimized.
- It is important that disinfectants and pH-adjusting chemicals be well mixed with the water at the point of dosing.
- Dosing systems, like circulation, should operate 24 h per day.

5.3 Filtration

Filtration is crucial to good water quality in general. If filtration is poor, clarity will be affected. Water clarity is a key factor in ensuring the safety of swimmers. Poor underwater visibility is a contributing factor to injuries (chapter 2) and is important to recognition of swimmers in distress or a body lying on the bottom of the pool.

Disinfection will also be compromised by particulates. Particles can shield microorganisms from the action of disinfectants. Alternatively, the disinfectants may react with certain components of organic particles to form complexes that are less effective than the parent compounds, or the disinfectants may oxidize the organic material, thereby eliminating disinfection potential (Department of National Health and Welfare, 1993).

Filtration is often the critical step for the removal of *Cryptosporidium* oocysts and *Giardia* cysts. It is also effective against microbes, notably free-living amoebas that harbour opportunistic bacteria, such as *Legionella* and *Mycobacterium* spp. *Cryptosporidium* oocysts are effectively removed by fine-grade diatomaceous earth filtration where the porosity of the filter is less than 4 µm (Lange et al., 1986). *Giardia* cysts are somewhat larger and are removed by filters with a porosity of 7 µm or less (section 3.3.4). Although the average pore size of a pool sand filter can be as large as 100 µm, there is no bottom limit to the size of particle that can be removed. With the aid of a coagulant (section 5.4) and an appropriate flow rate, suspended matter — including colloidal matter smaller than 1 µm — can be removed.

Some of the factors that are important to consider in the design of a filtration system include:

- *filtration rate*: Typically, the higher the filtration rate, the lower the filtration efficiency. Higher-rate filters do not remove particles and colloids as effectively as medium-rate filters, and the filters cannot be used with coagulants.
- *sand bed depth*: Sand filters are most commonly used in public and semi-public swimming pools. The correct sand bed depth is important for efficient filtration.
- *number of filters*: Pools will benefit greatly from the increased flexibility and safeguards of having more than one filter. In particular, pools can remain in use with a reduced turnover on one filter while the other one is being inspected or repaired. Filtered water from one filter can be used to backwash another.
- *backwashing*: The cleaning of a filter bed clogged with suspended solids is referred to as backwashing. It is accomplished by reversing the flow, fluidizing the sand and passing pool water back through the filters to waste. It should be initiated as recommended by the filter

manufacturer, when the allowable turbidity value has been exceeded or when a certain length of time without backwashing has passed.

In terms of effective disinfection, a useful, but not absolute, upper-limit guideline for turbidity is 0.5 nephelometric turbidity units (NTU), determined by the nephelometric method (ISO, 1999). For identifying bodies at the bottom of the pool, a universal turbidity value is not considered to be appropriate, as much depends on the characteristics of the individual pool, such as surface reflection and pool material/construction. Individual standards should be developed, based on risk assessment at each pool. One possibility is to use as a minimum the ability to see a small child at the bottom of the pool from the lifeguard position while the water surface is in movement, as in normal use (Health & Safety Commission, UK and Sport England, 1999). An alternative is to maintain water clarity so that lane markings or other features on the pool bottom at its greatest depth are clearly visible when viewed from the side of the pool. Operators could determine these indicators as a turbidity equivalent through experience and then monitor routinely for turbidity. The procedure that results in the more stringent turbidity guideline should be used.

5.4 Coagulation

Coagulants (or flocculants) enhance the removal of dissolved, colloidal or suspended material by bringing it out of solution or suspension as solids (coagulation), then clumping the solids together (flocculation), producing a floc, which is more easily trapped in a filter. Coagulants are particularly important in helping to remove the infective oocysts and cysts of *Cryptosporidium* and *Giardia*, which otherwise may pass through the filter.

Coagulant efficiency is dependent upon pH, which, therefore, needs to be controlled.

5.5 Dilution

Filtration and disinfection will not remove all pollutants. The design and operation of a swimming pool should recognize the need to dilute the pool water with fresh water. Dilution limits the build-up of pollutants from bathers (e.g., constituents of sweat and urine) and of the by-products of disinfection and various other dissolved chemicals.

To some extent, dilution can be effected through the replacement of water used in filter backwashing and by use of pool water for pre-swim showering.

5.6 Circulation and hydraulics

The purpose of giving close attention to circulation and hydraulics is to ensure that the whole pool is adequately served. Treated water must get to all parts of the pool, and polluted water must be removed — especially from areas most used and most polluted by bathers. If not, even good water treatment may not give good pool water quality. Conversely, good circulation hydraulics may allow an over-stretched water treatment system to produce good-quality pool water.

The design and positioning of inlets, outlets and surface water withdrawal are crucial. A deck-level system (pool water level with the surrounds), with a balance tank and pool surround collecting channels, is particularly efficient: almost all of the total circulation rate can be removed from the surface, where pollution is greatest (Gansloser et al., 1999). Carlson (1965) reported that the free chlorine level in the pool water is always lower at the air/water boundary layer than in deeper layers, caused in part by the high chlorine demand of organic pollutants (e.g., skin fats, body oils, dandruff, etc.) on the water surface. Most bacteria shed by the bathers are in saliva and mucus discharges that also occur near the surface.

The circulation rate is defined as the flow of water to and from the pool through all the pipework and the treatment system. The appropriate circulation rate depends, in most cases, on bathing load. There are, however, some types of pool where circulation rate cannot realistically be derived from bathing load — diving pools, for example.

Circulation rate is related to turnover period, which is the time taken for a volume of water equivalent to the entire pool water volume to pass through the filters and treatment plant and back to the pool. In principle, the shorter the turnover period, the more frequent the pool water treatment.

Turnover periods must, however, also suit the particular type of pool (see Box 5.1 for examples). Ideally, turnover can be designed to vary in different parts of the pool: longer periods in deep areas, shorter where it is shallow. Where pools have moveable floors, the turnover should be appropriate to the biggest bathing load the pool will have — i.e., at its shallowest. Localized reductions in turnover period may be required in leisure pools with irregular shapes and variable depth, where water volumes are low in relation to bather load.

Box 5.1: Examples of turnover periods for different types of pool

In the United Kingdom, the Pool Water Treatment Advisory Group has suggested the following turnover periods for different types of pools:

Pool type	Turnover period
Competition pools 50 m long	3–4 h
Conventional pools up to 25 m long with 1-m shallow end	2.5–3 h
Diving pools	4–8 h
Hydrotherapy pools	0.5–1 h
Leisure water bubble pools	5–20 min
Leisure waters up to 0.5 m deep	10–45 min
Leisure waters 0.5–1 m deep	0.5–1.25 h
Leisure waters 1–1.5 m deep	1–2 h
Leisure waters over 1.5 m deep	2–2.5 h
Spas	5–15 min
Teaching/learner/training pools	0.5–1.5 h
Water slide splash pools	0.5–1 h

Source: PWTAG, 1999

5.7 Bathing load

Bathing load is a measure of the number of people in the pool. All pools should identify and maintain a realistic relationship between bathing numbers and pool and treatment plant capacity. For a new pool, the bathing load should be estimated at the design stage.

The many factors that determine the maximum bathing load for a pool include:

- area of water — in terms of space for bathers to move around in and physical safety;
- depth of water — the deeper the water, the more actual swimming there is and the more area a bather requires;
- comfort; and
- pool type and bathing activity.

An example of maximum bathing load formulae used in the United Kingdom is given in Box 5.2.

Box 5.2: An example of bathing load formulae used in the United Kingdom

The maximum bathing load is sometimes defined as 1 bather per 3 m^2. This gives a maximum bathing load for the whole pool, regardless of depth, etc., and must in any case be modified in the light of local conditions.

As far as designing and operating pools are concerned, there are three maximum bathing load formulae that can be applied:

- shallow water (under 1 m) — 1 bather per 2.2 m^2;
- standing depth water (1–1.5 m) — 1 bather per 2.7 m^2; and
- deep water (over 1.5 m) — 1 bather per 4 m^2.

The bathing load obtained using these formulae:

- is the maximum bathing load of the pool *at any one time* (instantaneous bathing load);
- should not be exceeded; and
- should be used when designing a pool and working out the circulation rate, etc.

Source: PWTAG, 1999

An operational daily bathing load must be established that takes into account the capacity of the system to maintain good water quality, including bather cleanliness, the treatment system, the chemicals used and the dilution rate. Some experts have suggested, as a “rule of thumb,” that 25–50% of the instantaneous bathing load multiplied by 12 be used, assuming that the treatment plant operates for 24 h a day.

5.8 Accidental release of faeces or vomitus into pools

AFRs appear to occur relatively frequently, and it is likely that most go undetected. AFRs into swimming pools and spas can lead to outbreaks of infections associated with faecally derived viruses, bacteria and pathogenic protozoa (chapter 3). Vomitus may have a similar effect.

A pool operator faced with an AFR or vomitus in the pool water must act immediately.

If the faecal release is a solid stool, it should simply be retrieved quickly and discarded appropriately. The scoop used to retrieve it should be disinfected so that any bacteria and viruses adhering to it are inactivated and will not be returned to the pool the next time the scoop is used. As long as the pool is in other respects operating properly (disinfectant residuals, etc.), no further action is necessary. The same applies to solid animal faeces.

If the stool is runny (diarrhoea) or if there is vomitus, the situation is potentially hazardous. Even though most disinfectants deal relatively well with many bacterial and viral agents in AFRs and vomitus, the possibility exists that the diarrhoea or vomitus is from someone infected with one of the protozoal parasites, *Cryptosporidium* and *Giardia.* The infectious stages (oocysts/cysts) are resistant to chlorine disinfectants in the concentrations that are practical to use. The pool should therefore be cleared of bathers immediately.

The safest action, if the incident has occurred in a small pool, hot tub or whirlpool, is to empty and clean it before refilling and reopening. However, this is economically impossible in many larger pools.

If draining down is not possible, then the procedure given below — an imperfect solution that will only reduce but not remove risk — should be followed:

- The pool is cleared of people immediately.
- Disinfectant levels are maintained at the top of the recommended range.
- The pool is vacuumed and swept.
- Using a coagulant, the water is filtered for six turnover cycles. This could take up to a day and so might mean closing the pool until the next day.
- The filter is backwashed (and the water run to waste).
- The pool can then be reopened.

[N.B. The effectiveness of this procedure is currently being evaluated.]

The willingness of operators and lifeguards to act is critical and problematic. Pool operators are unlikely to know with certainty what has caused a diarrhoea incident, and a significant proportion of such diarrhoea incidents may happen without lifeguards being aware of them. The most important contribution a pool operator can make to the problem is to guard against it. There are a few practical actions pool operators can take to help prevent faecal release into pools:

- No child (or adult) with a recent history of diarrhoea should swim.
- Parents should be encouraged to make sure their children use the toilet before they swim.
- Thorough pre-swim showering is a good idea, and parents should encourage their children to do it — preferably by example. At the other extreme, washing babies' bottoms in the pool should be discouraged.
- Young children *should whenever possible* be confined to pools small enough to drain in the event of an accidental release of faeces or vomitus.
- Lifeguards should be made responsible for looking out for and acting on AFR/vomitus incidents.

5.9 Special case of spa pools

Spa pools have different operating conditions and present a special set of problems to operators. The design and operation of these facilities make it difficult to achieve adequate disinfectant residuals. They may require higher disinfectant residuals because of higher bathing loads and higher temperatures, both of which lead to more rapid loss of disinfectant residual.

Hot tubs and whirlpools and associated equipment create an ideal habitat for the proliferation of *Legionella* and *Mycobacterium.* In addition, *P. aeruginosa* is frequently present in whirlpools, and skin infections have been reported when the pool design or management is poor. A *P. aeruginosa* concentration of less than 1 per 100 ml should be readily achievable through good management practices. Risk management measures that can be taken to deal with these nonenteric bacteria, including ventilation, cleaning of equipment and verifying the adequacy of disinfection, are described in chapter 3.

Spa pools that do not use disinfection require alternative methods of water treatment to keep the water microbiologically safe. A very high rate of water exchange is necessary — even if not effective enough — if there is no other way of preventing microbial contamination. In spa pools where the use of disinfectants is undesirable or where it is difficult to maintain an adequate disinfectant residual, superheating spa water to 70 °C on a daily basis during periods of non-use may help to control microbial proliferation.

One example of procedures recommended to ensure good water quality in spa pools is given in Box 5.3. Some countries — in Europe, for example — recommend draining spas every day.

Box 5.3: An example of water purification standards for spa pools

Spa pools must be connected to a filter used solely for the spa system. The water recirculation equipment must be capable of recirculating the full water volume of the spa pool through the filter at a nominal minimum rate of once every 30 min. Spa pools should also be drained at least once a week to enable cleaning of their floors and walls and refilled with fresh water; in addition, they should be equipped with a weir offtake or skimming system that continuously takes water from the pool surface.

Source: Government of Victoria, 1999

To prevent overloading of spa pools, some countries recommend that clearly identifiable seats be installed for users; as well, a minimum pool volume for every seat, a minimum total pool volume and a maximum water depth can be specified (Deutsches Institut für Normung, 1997a).

5.10 Special case of vessel pools

Pools and spas on ships may use either seawater or potable water as the source water. The hydraulic and circulation system of the pool will necessitate a unique pool design, depending upon ship size and pool location. The filtration and disinfection systems will also require adaptation to the water quality. Flow-through seawater pools on cruise ships may become contaminated by polluted water in harbour areas and risk contamination from sewage discharge (see WHO *Guidelines on Water Safety and Sanitation on Cruise Ships*, in preparation).

Because of the presence of bromide ions in salt water, the dominant THM formed in the water and air of seawater pools on ships will be bromoform.

5.11 Air quality

Air quality (e.g., humidity, temperature, irritant chemicals) is important for bather comfort. The two areas of principal concern for health are *Legionella* and disinfectant by-products.

Rooms housing hot tubs and whirlpools should be well ventilated to avoid an accumulation of *Legionella* in the indoor air (see section 3.4.1).

Reducing exposure to disinfectant by-products in air should be pursued in order to minimize overall exposure to these chemicals, even if inhalation does not appear to be the dominant route of exposure (see chapter 4). As concentrations of disinfectant by-products decrease rapidly with height above the water, this may have implications for ventilation design, which involves both mixing and dilution (i.e., with fresh air).

5.12 Monitoring

Parameters that are easy and inexpensive to measure reliably and of immediate health relevance — such as turbidity, disinfectant residual and pH — should be monitored most frequently and in all pool types. Whether any other parameters — physical, chemical and microbiological — need to be monitored is in practice determined by management capacity, intensity of use and any regulatory requirements. However, microbiological monitoring at varying frequencies is generally needed in public and semi-public pools.

There should be pre-established (clear, written) procedures set up by managers for acting on the results of monitoring, including how to act on any unexpected results. Operators must know what to do themselves or how to ensure that some appropriate action is taken by someone else. Management should monitor data and test systems regularly and ensure that pool operators have taken appropriate remedial action.

5.12.1 Turbidity

Filtration is crucial to good water quality in general. If filtration is poor, clarity will be affected. Water clarity is a key factor in ensuring the safety of swimmers. Poor underwater visibility is a contributing factor to injuries (chapter 2) and is important to recognition of swimmers in distress or a body lying on the bottom of the pool.

Testing for turbidity is easy. Approaches to establishing appropriate, facility-specific turbidity standards are described in section 5.3. Exceedance of a turbidity standard suggests both a significant deterioration in water quality and a significant health hazard. Such exceedance merits immediate investigation and may lead to facility closure pending remedial action. If these turbidity equivalents are higher than 0.5 NTU, which is a useful upper-limit guideline for optimized water treatment, then the lower, more stringent guideline should be used.

5.12.2 Disinfectant residual

1) Guidelines

Disinfectant residuals should be as low as is consistent with satisfactory microbiological quality. For a conventional public or semi-public swimming pool with good hydraulics and filtration, operating within its design bathing load and turnover, experience has shown that adequate routine disinfection should be achieved with a free chlorine residual level of at least 1 mg/litre throughout the pool, or equivalent disinfection efficiency (see chapter 3). Free chlorine residuals well above 1 mg/litre should not be necessary anywhere in the pool unless the pool is not well designed or well operated — if, for example, circulation is too slow, distribution is poor or bathing loads are too heavy.

Free chlorine residuals above 5 mg/litre in swimming pool water may present a health-based hazard to users. The WHO drinking-water guideline for chlorine is 5 mg/litre (WHO, 1993), based on a TDI of 150 µg/kg of body weight and assuming 100% allocation of the TDI to drinking-water. A 60-kg adult would need to ingest about 2 litres of swimming pool water to exceed the TDI. On the other hand, a 10-kg child would need to accidentally or intentionally swallow only about a third of a litre of water to exceed the TDI, a circumstance that may in fact occur occasionally (see chapter 4).

For this reason, operators should attempt to maintain free chlorine residual levels well below 5 mg/litre. In pursuit of low operational costs and bather comfort, it is therefore recommended that operators aim for a chlorine disinfectant residual of 1 mg/litre throughout the pool. In a well operated pool, experience suggests that it is possible to do this with maximum levels at any single point always below 2 mg/litre for public pools and 3 mg/litre for semi-public pools.

Experience suggests that the combined chlorine residual (chloramines) is no more than half the free chlorine (and ideally 0.2 mg/litre) where pool water treatment is operating well. If the levels are high, then it is likely that there is too much ammonia coming from sweat and urine of the bathers, indicating that bathing loads or pollution from bathers may be too high or that dilution is too low.

Lower free chlorine residuals (0.5 mg/litre or less) will be required with the additional use of ozone. Higher levels (2–3 mg/litre) may be required for spa and hydrotherapy pools, because of higher bathing loads, higher temperatures, which lead to more rapid loss of disinfectant residual and growth of microorganisms, and, in the case of hydrotherapy pools, potentially increased risk of infection in users.

If the chlorine source is chlorinated isocyanurate compounds, then the level of cyanuric acid must also be monitored and controlled; if it becomes too high (above about 100 mg/litre), microbiological conditions may become unsatisfactory.

Recommended bromine-based disinfectant residuals in swimming pools range from 1 to 6 mg/litre (see Table 4.2). When bromine-based disinfectants are used in combination with ozone, the concentration of bromide ion should be monitored and maintained at 15–20 mg/litre at all times (Barlow, 1993). If BCDMH is the bromine source, the level of DMH must also be monitored; it should not exceed 200 mg/litre (PWTAG, 1999). Failure to maintain target residual disinfectant residuals should result in immediate investigation and follow-up testing. If residuals cannot be rapidly re-established and maintained, then full investigation of cause and prevention of repetition are merited, and public health authorities should be consulted in determining whether the facility should remain open.

2) Sampling and analysis

Disinfectant residuals should be checked by sampling the pool before it opens and after closing. The frequency of testing while the swimming pool is in use depends upon the nature and use of the pool. Testing may need to be done as often as once every 2 h at a heavily used public pool. All such tests must be carried out immediately after the sample is taken. Sampling may be done manually; however, instrumentation for the continuous monitoring of disinfectant residuals and pH values, which is normally linked to the chemical dosing system, provides a more even treatment of the pool water and a closer control.

Samples should be taken at various parts of the pool, at a depth of 5–20 cm (as most pollution occurs near the surface; see section 5.6), to select a point typical of the general concentration in the pool. It is good practice to include as a routine sampling point the area of the pool where, because of the hydraulics, the disinfectant residual is generally lowest. Occasional samples should be taken from other parts of the pool and circulation system.

The disinfectant residual tests must determine free chlorine. They are generally performed with simple test kits based on the *N*,*N*-diethyl-*p*-phenylenediamine (DPD) method, using either liquid or tablet reagents.

5.12.3 pH

The pH of swimming pool water must be adjusted to ensure efficient disinfection and because coagulants may be less effective if the pH value is outside of the recommended range.

In order to maintain the pH within the recommended range, regular measurements are essential, and either continuous or intermittent adjustment is usually necessary. For heavily used pools, the pH value should be measured continuously and adjusted automatically; for other pools, it is sufficient to measure the pH value regularly and adjust it intermittently. Occasionally, a pool will not require the addition of acid or alkali for pH control, due to a particular combination of water quality characteristics and disinfectant use. However, this cannot be reliably predicted and may not be stable, so it is essential to provide for the monitoring and dosing of pH adjustment chemicals.

The chemical required for pH value adjustment will generally depend on whether the disinfectant used is itself alkaline or acidic. Alkaline disinfectants — sodium and calcium hypochlorite, for instance — normally require only the addition of an acid for pH correction, usually a solution of sodium bisulfate, carbon dioxide or hydrochloric acid. Acidic disinfectants — chlorine gas and trichloroisocyanuric acid, for example — will normally require the addition of an alkali, usually a solution of sodium carbonate (soda ash), to raise pH.

pH testing is generally undertaken at the same time as disinfectant residual testing. Actions to be taken on failure to maintain pH within the target range are similar to those for disinfectant residual.

5.12.4 Oxidation–reduction potential

Continuous control of the oxidation–reduction potential (ORP) is considered useful by many experts. Together with pH and free chlorine, the ORP value gives an indication of the disinfection efficiency (Carlson et al., 1968; Jentsch, 1973). In chlorinated pools, ORPs of 750 mV (for pH 6.5–7.3) and 770 mV (for pH 7.3–7.8), measured against a silver/silver chloride reference electrode with potassium chloride electrolyte (Denecke and Althaus, 1986), are required to guarantee the safe inactivation of microorganisms (Deutsches Institut für Normung, 1997a).

5.12.5 Microbiological quality

There is limited risk of significant microbiological contamination and illness in a well managed pool with an adequate disinfectant residual, a pH value maintained at the recommended level, optimally operated filters and frequent testing of turbidity, disinfectant and pH. Nevertheless, samples of pool water should be monitored at appropriate intervals for microbiological parameters. Such tests do not guarantee complete microbiological safety but serve to provide information with which to judge the effectiveness of measures taken. Since the indicator organisms used are relatively sensitive to disinfection with, for instance, chlorine, their absence does not imply the absence of more resistant organisms. Oocysts and cysts of *Cryptosporidium* and *Giardia*, respectively, provide the most extreme example. In general, a routine monthly test during periods of heavy use will suffice once it has been established — perhaps by more frequent tests — that the situation at a facility is under control. Samples should also be taken before a pool is used for the first time, before it is put back into use after it has been shut down for repairs or cleaning, and if there are difficulties with the treatment system. Samples should also be tested when contamination is suspected (e.g., after an AFR) and as part of any investigation into possible adverse effects on bathers' health.

1) Indicator organisms

There are mixed opinions on the advantages and disadvantages of the various indicators of the microbiological quality of pool water. Some indicators/tests, such as heterotrophic plate count (HPC), provide a general indication of pool hygiene, including shed and regrowth organisms. Others are more specific for faecal contamination, such as thermotolerant ("faecal") coliforms, *E. coli* and enterococci/faecal streptococci. Keirn & Putnam (1968), for example, proposed that because staphylococci and streptococci are more resistant to chlorine than *E. coli*, they should be used as indicator organisms for pools. Martins et al. (1995) considered total viable count (HPC) and total coliforms to be the most cost-effective indicators. Ibarluzea et al. (1998) found that total coliforms, faecal coliforms and faecal streptococci were equally adequate as indicators of microbiological safety in indoor disinfected pools. For non-disinfected pools, *Standard Methods for the Examination of Water and Wastewater* (APHA, 1989) suggests that the primary indicators should be faecal coliforms for AFRs and staphylococci or *Pseudomonas* for non-faecal human contamination.

The sudden rise of an HPC that has been traditionally low should give rise to concern, even in the absence of a concomitant rise in the coliform count. It is recommended that HPC be measured in disinfected pools or spas but not in non-disinfected pools or spas and that testing for a faecal indicator organism should be undertaken in all pools and spas (disinfected or not).

Faecal coliform and *E. coli* concentrations of less than 1 per 100 ml should be readily achievable through good management practices. While enterococci/faecal streptococci are more resistant to disinfection by chlorine than are thermotolerant coliforms and *E. coli* and might, therefore, be preferred as a more robust indicator, less experience has accrued with their application to swimming pools, and it is not possible to indicate the maximum concentration that should be achieved through good practice.

If the HPC is not more than 10 cfu/ml following incubation at 37 °C for 24 h and there are no faecal coliforms or *E. coli* present, it can be assumed that the hygienic conditions and operational management of the pool were satisfactory at the time the sample was taken. If higher colony counts are occasionally found, this is acceptable as long as no faecal coliforms are present and the operating conditions of the pool are satisfactory. If, however, higher counts are found consistently, this suggests that operating conditions may be unsatisfactory and requires investigation and possibly remediation. If faecal coliform organisms are also present, this suggests the possibility of a serious defect in the pool operating system, such as a failure of the disinfection process and/or a problem with the chemical balance of the pool (including the pH value) or the filtration system, which will require immediate attention.

With some organic disinfectants — such as chlorinated isocyanurates and BCDMH — an elevated HPC is relatively common and often stable. However, if there is a significant change in the counts, action should be taken.

There is no general agreement as to the value of examining pool waters routinely for the presence of *Pseudomonas*. Testing for *P. aeruginosa* may be considered when there is evidence of operational problems such as failure of disinfection, affecting filters or water pipes, a deterioration in the quality of the pool water or known health problems.

If high counts are found — over 100 colony-forming units (cfu) per 100 ml — pool operators should check water clarity, disinfectant residuals and pH, resample, backwash thoroughly, wait one turnover and resample. If high levels of *P. aeuruginosa* remain, the pool should be closed and a thorough cleaning and disinfection programme initiated.

A guideline value for *P. aeruginosa* (less than 1 per 100 ml) has been proposed for continuously disinfected pools (see chapter 3). For non-continuously disinfected pools (i.e., without residual disinfectant), a guideline of less than 10 per 100 ml, which can reasonably be achieved through good operating practice, is more realistic. In such pools, testing for *P. aeruginosa* should be undertaken routinely, once per week. An alternative solution would be to shock disinfect pools and clean facilities daily during periods of non-use. For non-chlorinated spa pools, draining, cleaning and refilling the pools or, alternatively, heating water to 70 °C and cooling to normal operating temperature during non-use periods might be sufficient to control *P. aeruginosa* (as well as *Legionella* and *Mycobacterium*). These measures could also be used when levels of *P. aeruginosa* exceed 10 per 100 ml.

Staphylococci are almost invariably found in water when bathers are present. Testing pool water routinely for staphylococci, particularly *Staphylococcus aureus*, has been proposed as a suitable indicator of poor microbiological quality. However, it is proposed only as part of a wider investigation into the quality of the water when health problems associated with the pool are suspected. It has been suggested that a realistic limit is 30 staphylococci per 100 ml in no more than 15% of the samples taken during normal operation (Keirn & Putnam, 1968).

Hot tubs and whirlpools are a major route of exposure to *Legionella*, which thrive in the warm, nutrient-containing waters characteristic of spa pools. Infection occurs following inhalation of contaminated aerosols generated by the spas. Immunocompromised individuals are at particular risk. Although *Legionella* is susceptible to disinfection, spa characteristics make it difficult to maintain adequate disinfection residuals on a continuous basis. Frequent adjustment of pH and disinfectant residuals and filter backwashing are essential for controlling *Legionella* and other opportunistic pathogens in spas. Periodic draining, cleaning and refilling of spa pools may be necessary. Air handling equipment serving indoor spas should also be routinely serviced to prevent contamination. Routine testing for *Legionella* is not necessary but should be considered when conducting outbreak investigations.

2) Sampling

Recommendations regarding routine sampling of pools for testing of microbiological parameters are included in Table 5.1. Standard sampling procedures should be followed (see, for example, PWTAG, 1994).

Table 5.1: Recommended minimum sampling frequencies and indicators for routine microbiological testing during normal operation

	Heterotrophic plate count	Faecal indicator (e.g., *E. coli*)	*Pseudomonas aeruginosa*	*Staphylococcus aureus*
Disinfected pools, public and heavily used	weekly	weekly	when situation demands	when situation demands
Disinfected pools, semi-public	monthly	monthly	when situation demands	when situation demands
Non-disinfected pools	n/a	weekly	weekly	when situation demands
Hot tubs, whirlpool spas	n/a	weekly	weekly	when situation demands
Teaching and hydrotherapy pools	weekly	weekly	when situation demands	when situation demands

Notes:
1. Samples should be taken when pool is heavily loaded.
2. Sampling frequency should be increased if operational parameters (e.g., turbidity, pH, disinfectant residual, continuous filtration) are not maintained within target ranges.
3. Sample numbers should be determined on the basis of pool size and complexity and should include point(s) representative of general water quality and likely problem areas.

The most appropriate site for taking a single sample is where the water velocity is low, away from any inlets. Depending on the size of the pool, it may be advisable to take samples from other multiple sites. Many leisure pools will have additional features, such as flumes, islands and backwaters with a complex system of water flow; representative samples should be taken.

Misleading information on pool water quality will result from incorrect sampling procedures. Sample containers must be of a material that will not affect the quality of the sample either microbiologically or chemically. Although a good-quality glass container will meet these requirements, the risk of breakage in the pool environment has favoured the use of shatterproof plastic-coated glass containers. All-plastic containers can be used provided they do not react with microorganisms or chemicals in the water; not all are suitable. The required capacity is usually 200–500 ml (Bartram & Rees, 2000).

For microbiological examination, the bottle must be sterile and contain an agent that neutralizes the disinfectant used in the pool water. Sodium thiosulfate (18 mg/litre) is the agent used for chlorine- and bromine-based disinfectants. Clearly, the testing laboratory must be advised before sampling if any other disinfectant is being used (PWTAG, 1999).

To take the microbiological sample, the stopper is first removed with one hand, making sure that no contamination of the bottle or cap occurs. The bottle is then immersed to 150 mm below the surface of the water when the bottle is tilted to face horizontally towards the direction of the flow and allowed to fill. Once removed from the water, the stopper must be replaced and the sample transferred to the laboratory immediately. This is a difficult technique, as the loss of thiosulfate must be prevented during sample collection. An alternative is to collect the sample in one sterile dipper or bottle and then immediately pour it into a second sterile bottle containing thiosulfate.

Bacteria in pool water samples and especially those from disinfected pools may be “injured,” and normal analytical “resuscitation” procedures should be fully adhered to.

5.12.6 Miscellaneous

Several parameters are important for operational purposes. These include:

- *alkalinity*: Alkalinity is a measure of the alkaline salts — primarily bicarbonates and carbonates — dissolved in the water. The higher the alkalinity, the more resistant the water is to large changes in pH in response to changes in the dosage levels of disinfectant and pH correction chemicals. If the alkalinity is too high, however, it can make any necessary pH adjustment difficult.
- *calcium hardness*: Calcium hardness is an operational measure that is particularly relevant to swimming pools. If hardness is below about 40 mg/litre as calcium carbonate, the water is likely to be corrosive to the fabric of the pool plant. By about 75 mg/litre, a protective scale can start to form; thus, as far as corrosion is concerned, there should be no need to boost hardness beyond that level. However, given some uncertainty about the cause of grout loss in pools, an upper figure of 150 mg/litre (or the use of epoxy grout) has been suggested.
- *total dissolved solids*: Total dissolved solids (TDS) is the sum of the weight of soluble material in water. Disinfectants and other pool chemicals as well as bather pollution will increase TDS levels. The real value of detecting an increase in TDS levels is as a warning of overloading or lack of dilution, and TDS levels should be monitored by comparison between pool and main water. If TDS is high, dilution is likely to be the correct management action.

5.13 References

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