Public Swimming Pool and Spa Pool Advisory Document

NSW GOVERNMENT | Health

Public swimming pool and spa pool advisory document

HEALTH PROTECTION NSW
73 Miller Street
NORTH SYDNEY NSW 2060
Tel. (02) 9391 9000
Fax. (02) 9391 9101
TTY. (02) 9391 9900
www.health.nsw.gov.au

For more information, please contact your local Public Health Unit whose contact details can be found at www.health.nsw.gov.au

Suggested citation: Health Protection NSW. Public swimming pool and spa pool advisory document. Sydney: 2013.

SHPN (EH) 130037
ISBN 978 1 74187 896 7

April 2013

Acknowledgements

There were many contributions made in the development of this advisory document. In particular NSW Health would like to acknowledge the Swimming Pool Industry Group, and the organisations below who provided direction and guidance.

Aquatic and Recreation Institute
Collingridge and Associates
Fulham Engineering Services Pty Ltd
Pallintest Australia
ProMinent Fluid Controls Pty Ltd
Stevenson and Associates Pty Ltd
Siemens Water Technologies
Trisley's Hydraulic Services
Bellingen Shire Council
Leichhardt Municipal Council
Ryde City Council
Shoalhaven City Council
Warringah Council
Poolwerx
Tim Batt Water Solutions Pty Ltd

Swimming is an important recreational activity. Learning to swim prevents drowning. Swimming promotes good physical, mental and cardiovascular health. In properly managed pools the benefits of swimming far outweigh any risk.

(WHO 2006)

Contents

Quick Start for Pool Operators

The three most important parts of this advisory document for pool operators are:

- Chemical criteria
- Chemical testing
- Microbiological criteria and sampling

A. Chemical criteria

The mandatory Chemical Criteria is specified in Schedule 1 to the Public Health Regulation 2012. Schedule 1 can be found at:
http://www.health.nsw.gov.au/environment/publicpools/Documents/public-health-reg-2012-schedule_1.pdf

NSW Health only recommends the use of chlorine or bromine based disinfection systems for public swimming pools and spa pools. These systems rely on proper concentrations of pH and reserve alkalinity. It is essential that pool operators also read section 5.2 of Chapter 5.

B. Chemical testing

The minimum mandatory requirements for chemical testing are also specified in Schedule 1 mentioned above. The frequency of pool testing as best practice is outlined in section 5.6 of Chapter 5. Sampling location is discussed in section 5.7, testing equipment in section 5.8 and record keeping in section 5.10.

C. Microbiological criteria

The Microbiological criteria are specified in Box 3.1 of Chapter 3. It is important for pool operators to read all of Chapter 3.

D. Fact sheets

A series of fact sheets which complement this Advisory Document can be found at:
http://www.health.nsw.gov.au/environment/publicpools/Pages/default.aspx

E. Pool occupiers information sheet

Information Sheet Number 4 for occupiers of public pools is provided at:
http://www.health.nsw.gov.au/phact/Documents/is4-public-pools.pdf

After these essential sections, it is recommended that Chapter 1 (Introduction), Chapter 4 (Disinfection), Chapter 6 (Managing water quality) and Chapter 8 (Cryptosporidium risk management) be studied. Finally, the Contents should be consulted for matters of additional interest.

CHAPTER 1

Introduction

1.1 Overview

This chapter introduces the 2013 *Public Swimming Pool and Spa Pool Advisory Document* by explaining its purpose, scope and application. This chapter also explains that the disease risk from swimming pools is always present no matter how well a pool is disinfected and its patrons are managed. There is a brief overview of the public health legislation framework to control transmission of disease in public swimming pools. A distinction is drawn between the role of NSW Health and the Australian Pesticides and Veterinary Medicines Authority (APVMA) in the approval of disinfectants which may be used in a swimming pool. At the end of this chapter, advice is available to assist in navigation of the NSW Health website for pools.

1.2 Purpose

The primary purpose of the advisory document is to provide information and guidance to pool operators, authorised officers (also known as environmental health officers), pool consultants and other swimming pool industry stakeholders on the appropriate modern standards to design, operate and maintain healthy swimming pools and spa pools.

The secondary purpose is to complement public health legislation, particularly the prescribed operating requirements in Schedule 1 to the *Public Health Regulation 2012*.

Disinfection is critical to prevent the survival and growth of micro-organisms in swimming pools and spa pools. The quality of incoming water supply, efficient filtration, well designed circulation and distribution systems, and an optimum turnover rate to deliver clean clear water are equally important. Client hygiene management is also an important aspect of disease minimisation. Disease minimisation and water quality are the core themes of the advisory document.

The most commonly known micro-organism capable of causing large outbreaks in public swimming pools is *Cryptosporidium.* Outbreaks of cryptosporidiosis are a problem in public swimming pools because *Cryptosporidium* is chlorine resistant and is easily transmitted by infants who are not toilet trained. The advisory document highlights minimising the risk of *Cryptosporidium* contamination in public swimming pools and spa pools.

The advisory document is, where possible, evidence based and risk based. The recommended frequency of chemical and microbiological sampling has been reviewed to reflect this risk-based approach. This approach means that high-risk heated pools (particularly spas and hydrotherapy pools) should be tested more frequently and low-risk automatically-dosed pools (such as diving pools) less frequently. A chapter is included on risk management of pool operations.

Although scientific evidence suggests that the emerging issue of disinfection by-products are unlikely to cause health risks in properly managed pools, some mention is made of them. Included in emerging issues are those of recycling backwash water and rainwater harvesting.

The advisory document provides comprehensive information sufficient to fulfil an identified industry need for informing operators of pools who may not have had the opportunity of formal education in swimming pool matters.

1.3 Scope and application

This advisory document has a wide informative scope and some information is provided on the derivation of disinfection concentrations. For example, information is provided on the effect of pH on chlorine disinfection and the derivation of free chlorine and pH values.

The advisory document is more relevant to those swimming pool and spa pool operators to whom the public health legislation applies. Such pools are referred to as public pools. From 1 March 2013, occupiers of premises containing public swimming pools or spa pools must notify their local council of the pool's existence and comply with the "prescribed operating requirements". The prescribed operating requirements are set out in Schedule 1 of the Public Health Regulation. http://www.health.nsw.gov.au/environment/publicpools/Documents/public-health-reg-2012-schedule_1.pdf

It is an offence not to comply with the prescribed operating requirements and an authorised officer may issue an improvement notice for failure to comply. In serious cases, a failure to comply with the prescribed operating requirements may lead to a prohibition order or closure order being issued, closing down the pool. The advisory document, therefore, provides an understanding of what constitutes the prescribed operating requirements and explains chemical parameter values for disinfectants and pH levels for various circumstances.

An emerging type of swimming pool is the multi-residential pool such as those associated with apartments or town house developments. While such pools are not public swimming pools under the Public Health Act, they can still pose risks in terms of bather risk. The advisory document is equally applicable to this situation, but in a non-regulatory and advisory sense.

Authorised Officers (or Environmental Health Officers) should use the document to assist in developing skills in determining pool water quality, to determine when there may be a risk to public health and therefore to determine the nature of any enforcement action, if necessary.

1.4 Disease risk from swimming pools

Disease transmission, even in the best operated pool is always possible. At best, the time taken to transmit a disease can only be minimised to a fraction of a minute because it takes time for a disinfectant to kill or inactivate micro-organisms. There is no instantaneous kill of micro-organisms and swimming pools cannot be made sterile. The advisory document provides information about conditions under which a fast kill of disease-causing micro-organisms can realistically be achieved.

Public pools are more likely to be contaminated with a greater diversity of disease causing micro-organisms than single domestic swimming pools. This is because public pools are used by unrelated people and are more likely to have higher bather loads. Pathogenic (disease causing) micro-organisms must be quickly and effectively killed in the pool water in which they are introduced, otherwise a disease may be transmitted. The swimming pool or spa pool needs to be designed and operated to enhance the action of the disinfectant.

All public swimming pools and spa pools must be equipped with effective water circulation, filtration, disinfectant, and pH control systems. Ideally, the disinfection system and pH systems should be automatically controlled. Routine hand, drip or slug dosing of any chemical directly into an occupied swimming pool or spa pool from a container is not acceptable and is dangerous. Similarly, floating block dispensers are not considered appropriate.

1.5 Legislation

The *Public Health Act, 2010*, was commenced on 1 September 2012. Sections 34 to 37 apply to public swimming pools and spa pools. Section 35 however commences on 1 March 2013. Under the Act, a public swimming pool means a swimming pool or spa pool to which the public is admitted, whether free of charge, on payment of a fee or otherwise, including those swimming pools and spa pools:

- To which the public is admitted as membership of a club,
- Provided at a workplace for the use of employees,
- Provided at a hotel, motel or guest house or at holiday units, or a similar facility, for the use of guests, and
- Provided at a school or hospital,

but not including a pool situated on private residential premises.

The *Public Health Act* and *Public Health Regulation* set out specific requirements for occupiers of premises containing public swimming pools and spa pools and there are offences for non compliance. In particular:

- An occupier must give notice of the pool's existence to their local council (this requirement commenced on 1 March 2013)
- An occupier must comply with the prescribed operating requirements, which are set out in Schedule 1 of the Public Health Regulation (this requirement commences on 1 March 2013)
- The occupier must not allow a person to use the pool unless the water is disinfected in such a way as to minimise the transmission of disease to users of the pool

- The occupier must ensure that the pool surrounds, including any toilets and change rooms, are kept clean and in such condition as to minimise the transmission of disease.

Authorised Officers of both NSW Health and local councils are empowered to inspect public pools. As well as being an offence, a failure to comply with prescribed operating requirements could lead to an improvement notice directing compliance. If there is a breach of a prescribed operating requirement and the pool poses a serious risk to public health, a prohibition order may be served on the occupier to close public swimming pools and spa pools to prevent or mitigate a serious risk to public health. There is also power under the Public Health Regulation to close down a public pool or order public health action to be taken in relation to a pool that poses a risk to the public even if the prescribed operating requirements are being met.

The prescribed operating requirements for public pools can be found at *Schedule 1* of the Regulation. http://www.health.nsw.gov.au/environment/publicpools/Documents/public-health-reg-2012-schedule_1.pdf
The prescribed operating requirements require that pools may only be disinfected with chlorine or bromine using automated or continuously metered dosing systems. Dosing systems are discussed in Section 6 of this document. Disinfectant, temperature, pH, alkalinity, ozone and cyanuric acid parameters, testing requirements are also specified in Schedule 1.

The former "Guidelines for Disinfecting Public Swimming pools and Spa Pools – June 1996" have been withdrawn as they are no longer valid.

NSW Health is not an approval authority. It does not have the power to approve of chemicals, disinfectants, pool design or pool operational activities. NSW Health does not have the capacity to become involved in pool design or operation. The legal function of NSW Health and local councils is to monitor and determine public health risk and act accordingly to require the abatement of the public health risk in public pools.

1.6 Australian Pesticides and Veterinary Medicines Authority (APVMA)

Before swimming pool disinfection products can be sold, supplied, distributed or used in Australia, they must be registered by the APVMA, a Commonwealth agency based in Canberra. The registration process is governed by Commonwealth legislation and undertaken according to accepted scientific principles and through rigorous independent analysis by several government agencies and the APVMA. A list of approved sanitisers is provided on the APVMA website at:
http://www.apvma.gov.au/.

The use of APVMA unapproved packaged disinfectants in any public swimming pool or spa pool is not supported by NSW Health. Additionally, the only future disinfectants that will be recognised as primary disinfectants by NSW Health will be those which have been independently tested against the "APVMA Guide for Demonstrating Efficacy of Pool and Spa Sanitisers". This document can be accessed on the APVMA website above or on the NSW Health website below.

1.7 NSW Health website

The URL for the NSW Health is:
http://www.health.nsw.gov.au/

To navigate to the Swimming Pools and Spa Pools page click on "A to Z" on the blue banner and then click on "S" and finally click on "Swimming pools and spas".

CHAPTER 2

Microbial health risks and transmission

2.1 Overview

This chapter describes the groups of micro-organisms which may be introduced into the swimming pools and spa pools. The diseases caused by these micro-organisms and their probable modes of transmission are discussed.[1]

2.2 Micro-organisms

The main groups of micro-organisms associated with contamination of swimming pools and spa pools are listed below. Contamination of the pool may be classified as:

- Faecally derived, e.g. from bathers, animals or a contaminated water source, or
- Non-faecally derived, e.g. shedding from human skin, mucus, vomit or other secretions, or from animals, stormwater runoff and windblown.

2.2.1 Viral pathogens

Viruses cannot multiply in water and therefore their presence must be as a result of direct contamination.

i) Adenovirus: Most viral outbreaks linked to swimming pools have been attributed to adenovirus and were associated with inadequate disinfection.[2] There are over 50 types of adenoviruses[3]; and many may cause enteric infections but some are associated with respiratory and eye infections. Outbreaks of pharyngo-conjunctivitis (sore throat and sticky eyes) have been associated with adenovirus linked to swimming pools.

ii) Hepatitis A: Hepatitis A virus has been linked to three major outbreaks associated with swimming in a public swimming pool in recent times. In 1991 there was an outbreak in the USA, thought to have been caused by sewage contamination which resulted in 20 cases of hepatitis A virus infection. Another outbreak occurred in 1994 in Hungary when 31 children were hospitalised following swimming in a non-chlorinated pool during a holiday camp. The third documented outbreak was in Australia in 1997 when six boys became ill following 'whale spitting' in a public spa pool although chlorine concentration in this pool was reported to have met local health standards.[4]

The recommended levels of chlorination are effective in destroying the hepatitis A virus. Therefore outbreaks should not occur in properly managed pools that are always maintained above the required minimum disinfectant concentrations.

iii) Norovirus: There have been few reports of disease outbreaks related to norovirus (previously known as Norwalk virus or Norwalk-like virus). Kappus et al (1982) reported a gastroenteritis outbreak in Ohio, USA, affecting 103 students and teachers following swimming in a local pool.[5] In 2004, Maunula et al reported a similar outbreak in Helsinki, Finland, associated with norovirus contracted from a wading swimming pool.[6] All these cases occurred due to an inadequate system of disinfection, water quality monitoring and maintenance.

iv) Enterovirus: This group of viruses includes polioviruses, echoviruses and coxsackieviruses. The only documented enterovirus infection associated with a public swimming pool was reported by Kee et al in 1994. This outbreak caused vomiting, diarrhoea and headache in 33 people following swimming in an outdoor swimming pool. Echovirus was found to be the causative agent, and although disinfectant concentration was maintained according to health requirements, it was inadequate to contain the spread of the micro-organism due to the large numbers present in the vomit. Under such circumstances, a contaminated pool should be shut down until the contaminant is inactivated.

v) Papillomavirus: Papillomavirus causes warts and has been associated with contaminated wet surfaces. An investigation of an outbreak of 221 students found that the floors of the change rooms were the primary source of transmission.[7]

vi) Molluscipoxvirus: Molluscipoxvirus causes white or skin-coloured papule lesions (small, solid and usually conical elevation of the skin) mainly in children. The lesions are found on the hands, forearms and faces of swimmers, gymnasts and other athletes. The link between swimming and the disease, molluscum contagiosum, was confirmed in a sample of 198 patients in Princess Alexandra Hospital, Woolloongabba, Queensland. Swimming in a school swimming pool and sharing a bath sponge with an infected person were found to be the two more significant factors.[8]

2.2.2 Bacterial pathogens

i) *Shigella:* An outbreak of shigellosis was associated with swimming in a fill-and-drain wading pool in the USA. This outbreak resulted in 69 people becoming ill with suspected shigellosis, 26 cases of which were confirmed as *S. sonnei* by the laboratory (MMWR 2001). The pool was not disinfected and *Escherichia coli* and thermotolerant coliforms were also isolated from the pool water. The source of transmission was suspected to have been bathers with diarrhoea. The infective dose for *Shigella* is between 10 and 100 micro-organisms.

ii) *Escherichia coli O157:* Unlike most strains of *E. coli, E. coli O157* does not produce the enzyme glucuronidase and does not grow well at 44.5°C. As a result, it may not be detected using the normal method of analysis for indicator micro-organisms. *E. coli O157* causes non-bloody diarrhoea which may progress to bloody diarrhoea and haemolytic-uraemic syndrome (HUS). Some fatalities have been recorded. Approximately 5-10% of cases of *E. coli O157* infection develop HUS. Infants, young children and elderly people are particularly vulnerable. There have been outbreaks of infection associated with children's paddling pools. Most of these outbreaks followed a faecal accident in poorly disinfected pools.[9,10]

iii) *Pseudomonas aeruginosa:* *P. aeruginosa* is an opportunistic pathogen capable of metabolising a variety of organic compounds and is slightly resistant to a range of antibiotics and disinfectants. It is widely found in vegetation, soil and the aquatic environment. However, the predominant source of contamination of pools and spas is shedding from infected humans.

In swimming pools and spa pools, the primary health effects caused by *P. aeruginosa* are folliculitis and ear infection, although it has also been identified as the causative agent of eye, urinary tract, respiratory tract and wound infections. In serious cases it may also cause pneumonia.

The micro-organism is particularly problematic in warm spas as the high temperature of about 37°C and water turbulence are selective for its proliferation while suppressing the growth of other environmental microflora. *P. aeruginosa* has been found to colonise moist areas surrounding pools such as decks, benches and floors. It has also been found on pool surfaces, pool inflatable toys and within biofilms in filters, pipes and drains. Proper cleaning and disinfection (superchlorination) may be needed to prevent and control the growth of this micro-organism. It is difficult to maintain adequate disinfection levels constantly in spa pools because of the high temperature, heavy bather loads and water turbulence unless a reliable automatic disinfection system is installed.

iv) *Legionella:* *Legionella* bacteria are commonly found in natural sources of freshwater and also in man-made warm water systems and cooling water (tower) systems. They may also be found in moist soil.

L. pneumophila serogroup 1 is most frequently associated with human disease. There are two forms of *Legionella* infection: a serious pneumonic form known as Legionnaires' disease and a less debilitating form called Pontiac fever. *Legionella* infects humans through inhalation of infective aerosols created under specific conditions. The micro-organism is not known to cause disease by ingestion and there is no person-to-person transmission.

The majority of outbreaks have been associated with air conditioning water cooling systems. Showers may also pose a high risk of infection. Most of the reported legionellosis associated with recreational water occur in hot tubs and natural thermal spas.[11-13] Water spray from cooling towers and water agitated in spas may produce aerosols. Water from warm water systems can also form aerosols in showers, through nozzle heads or splashing in sinks and baths. Outbreaks of Legionellosis are rarely associated with properly disinfected spas. *Legionella* are easily destroyed by swimming pool chlorine and bromine disinfectants and therefore this organism should not present a problem in properly managed pools.

v) *Staphylococcus aureus:* *S. aureus* is a human commensal bacteria, present as part of the normal microflora of the nasal mucosa, the skin, and in the faeces of healthy individuals. It is thought to be the causative agent of most skin, wound, eye, ear and urinary infections in swimming pools.[14,15] Studies have shown that 50% or more of the total staphylococci isolated from swimming pool waters is *S. aureus*.[16]

Although *S. aureus* have been found in chlorinated swimming pools[17] maintaining a residual chlorine level of greater than 1 mg/L should eradicate the micro-organism.

vi) *Mycobacterium* spp.: Species of mycobacteria, other than the strictly pathogenic *M. tuberculosis*, are known as atypical mycobacteria. They are widely distributed in the aquatic environment. *M. avium* has been linked to hypersensitivity pneumonitis and possibly pneumonia following inhalation of contaminated aerosols generated by a spa pool.[18] *M. marinum* has been found to be responsible for localised lesions of the skin, especially on abraded elbows and knees.[19] This condition is referred to as swimming pool granuloma. The likely source of infection is contaminated pool surfaces as mycobacteria have been found to proliferate in these areas. Regular disinfection of pool surfaces and other moist areas surrounding pools is a good control measure. Regular superchlorination is also recommended to remove any biofilms which may harbour this micro-organism.

2.2.3 Protozoan pathogens

i) *Cryptosporidium:* There are several species of *Cryptosporidium* with *C. parvum* identified as the cause of a diarrhoeal illness in humans called cryptosporidiosis. This obligate protozoan parasite invades and multiplies in the gastro-intestinal tract of infected cattle, sheep and humans. It causes illness and produces oocysts, the infective form of the parasite. Large numbers of oocysts are excreted in faeces to the environment, including in water, where they can survive for a long time. As oocysts are highly resistant to standard levels of chlorine and bromine used for pool disinfection, transmission of the micro-organism in public swimming pools and spas can pose a serious public health risk, particularly to children and immuno-compromised persons. Mechanisms of transmission include faecal-oral, person to person, animal to person, waterborne and food borne. As the oocysts are very small (4-6 microns), highly chlorine resistant, and may persist in the pool water for days, filtration systems are unable to quickly remove the oocysts from pool circulation due to the principle of successive dilution (see Chapter 7.3).

Outbreaks of cryptosporidiosis have been reported around the world. The most infamous occurred in Milwaukee, USA in 1993 when about 403 000 cases were linked to the contamination of drinking water supplies[20]. Contaminated public swimming pools and other recreational water facilities have also been related to several outbreaks, including some in Australia. Between December 1997 and April 1998 over 1000 cases were notified in NSW, Queensland and the Australian Capital Territory where investigations implicated a number of pools to be a common source of contamination.[21]

In December 1996, public health legislation was amended requiring cases of cryptosporidiosis to be notifiable to NSW Health. Laboratories that detect *Cryptosporidium* in faecal samples must also notify NSW Health which may then carry out an investigation if warranted.

Cryptosporidium risk management in public swimming pools and spa pools is considered in more detail in Chapter 8.

ii) *Giardia:* *Giardia* is similar to *Cryptosporidium*, as *Giardia* species also form a cyst form that is resistant to chlorine. *Giardia* have been linked to outbreaks of gastroenteritis in public swimming pools.[22-24] It has a low infective dose of approximately 25 cysts[25] and is shed in large numbers in the faeces of infected people. However, most of the documented outbreaks of gastroenteritis in the swimming environment are *Cryptosporidium* related because its oocysts are more chlorine resistant than *Giardia* cysts. Giardiasis cases are also notifiable to NSW Health.

iii) *Naegleria fowleri:* This is a free-living amoeba, which causes primary amoebic meningo-encephalitis (PAM), a rare, but serious illness. Fortunately there have been no recent documented cases linked to swimming pools that are chlorinated. The micro-organism is thermophilic and thrives in nature in mineral springs, thermal bores, rivers and lakes. Cases of PAM have been linked to swimming in such places.

iv) *Acanthamoeba* spp.: Some species of *Acanthamoeba* are opportunistic pathogens and are found free-living in soil and all aquatic environments including chlorinated swimming pools. However, human contact with the micro-organism rarely leads to infection. Pathogenic species of *Acanthamoeba* cause granulomatous amoebic encephalitis (GAE) and inflammation of the cornea (keratitis).[26-28] Evidence suggests that properly maintained swimming pools are unlikely to be a source of infection in healthy individuals. There may however be an increased risk of GAE in immunosuppressed individuals and for people who wear contact lenses.

2.2.4 Fungal pathogens

***Trichophyton* spp. and *Epidermophyton floccosum*:** *Trichophyton* spp and *Epidermophyton floccosum* are fungal species that cause superficial infections of the hair, fingernail or skin. The most common infection is *Tinea pedis* or athletes foot. Symptoms include maceration, cracking and scaling of the skin, with intense itching. Transmission of the disease is normally by direct person-to-person contact. In swimming pools, infection usually arises from contact with contaminated surfaces, especially wet floors within shower rooms and change rooms.

To prevent transmission of fungal diseases, people with severe infections should seek medical treatment and should not use public swimming pools or spa pools. Pool operators should ensure proper cleaning and disinfection of surfaces, particularly floors. Patrons should be encouraged to wear sandals. In addition, the provision of PVC floor mesh mats may assist in maintaining hygienic conditions within change rooms.

A summary of the pathogenic micro-organisms which may be transmitted in swimming pools, the infection they cause and their source of contamination is outlined in Table 2.1 following.

Table 2.1: Pathogenic microbes associated with swimming pools

Organism	Infection	Source
Non-faecally derived bacteria		
Legionella spp.	Legionellosis (Pontiac fever and Legionnaires' disease)	Aerosols from spas and HVAC systems; Inadequate disinfection Poorly maintained showers or heated water systems
Pseudomonas aeruginosa	Folliculitis (spas) Swimmer's ear (pools)	Bather shedding in pool and spa waters and on wet surfaces around pools and spas
Mycobacterium spp.	Swimming pool granuloma Hypersensitivity; pneumonitis	Bather shedding on wet surfaces around pools and spas Aerosols from spa and HVAC systems
Staphylococcus aureus	Skin, wound and ear infections	Bather shedding in pool water
Leptospira spp.	Aseptic meningitis; Haemorrhagic jaundice	Pool water contaminated with urine from infected animals
Non-faecally derived viruses		
Adenoviruses	Pharyngo-conjunctivitis (swimming pool conjunctivitis)	Other bathers with infection
Molluscipoxvirus	*Molluscum contagiosum*	Bather shedding on benches, pool or spa decks, and swimming aids
Papillomavirus	Plantar wart	Bather shedding on pool and spa decks and floors in showers and changing rooms
Non-faecally derived protozoa		
Naegleria fowleri	Primary amoebic meningoencephalitis (PAM)	Pools, spas and natural spa water and pipes and other components
Acanthamoeba spp.	*Acanthamoeba keratitis* Granulomatous amoebic encephalitis (GAE)	Aerosols from HVAC systems
Plasmodium spp.	Malaria	Seasonally used pools may provide a breeding habitat for mosquitoes carrying *Plasmodium*
Non-faecally-derived fungi		
Trichophyton spp. *Epidermophyton floccosum*	Athlete's foot (*Tinea pedis*)	Bather shedding on floors in change rooms, showers and pool or hot tub decks
Faecally excreted viruses		
Adenovirus	Pharyngo-conjunctivitis	Nasal and eye secretions
Norovirus	Gastroenteritis	Faecal and vomit accidents
Hepatitis A virus	Hepatitis A (gastroenteritis)	Faecal accidents
Enterovirus (echovirus)	Gastroenteritis	Faecal and vomit accidents
Faecally excreted bacteria		
Shigella	Shigellosis (gastroenteritis)	Faecal accidents
E. coli	Gastroenteritis	Faecal accidents
Faecally-derived protozoa		
Giardia	Giardiasis (gastroenteritis)	Faecal accidents
Cryptosporidium	Cryptosporidiosis (gastroenteritis)	Faecal accidents

HVAC = Heating, ventilation and air conditioning

Source: adapted from WHO 2006[2]

2.3 Disease transmission theory

For a disease transmission episode to occur there must be three factors present at the one time as shown in the disease transmission pathway:

Source of pathogen → Transmission pathway → Susceptible host

Consider the transmission of the protozoan parasite *Cryptosporidium* in a swimming pool:

- There must be a **source** of pathogenic micro-organisms. In this case, the source is most likely faecal material from a person with infection, such as a non-toilet-trained infant, who has defecated into the pool. However, a source could also be an adult recovering from cryptosporidiosis and who is still shedding oocysts and who has not showered properly before entering the pool.
- The **transmission pathway** is the through the swimming pool water. Residual disinfectant must have sufficient time to disinfect the faecal material. It is very difficult in swimming pool water to disinfect faecal material which shields *Cryptosporidium* oocysts. Disinfection may take more than a day. Disinfection of *E. coli* could take less than one minute at recommended concentrations of chlorine or bromine.
- The **susceptible host** is a person in the swimming pool water capable of developing an infection.

If one of the above three factors is not present then transmission of disease will not occur. In Australia most of the effort to prevent transmission has concentrated on the transmission pathway i.e. the swimming pool. It is equally important to concentrate on the source of the pathogen by requiring all swimmers to toilet and shower before entering the pool. Infection in the susceptible host cannot be controlled because there is no vaccine.

2.4 Transmission of micro-organisms in swimming pools

Pathogenic micro-organisms can be transmitted in swimming pools from the ears, eyes, respiratory tract, skin, gastro-intestinal and urogenital tract of people with infection. Some micro-organisms, such as *Legionella* and *P. aeruginosa* are natural inhabitants of warm water environments and therefore these pathogenic micro-organisms are likely to proliferate if introduced into poorly disinfected pools.

Swimming pools and spa pools are often associated with outbreaks of infectious diseases. Commonly, these outbreaks occur in poorly chlorinated pools.[29,30] However, outbreaks of some micro-organisms, such as the protozoan parasite *Cryptosporidium*, are most likely to occur in pools following faecal accidents from infants who are not toilet trained (Furtado 1998; Hunt 1994; Sundkvist 1997; Bell 1993). Toddlers' pools are more often associated with outbreaks of infectious diseases[10,31,32] and this is supported by other studies that have found high counts of thermotolerant coliforms in pools used by toddlers.[33]

In NSW from December 1997 to April 1998, there was a state wide outbreak of 1060 laboratory-confirmed cryptosporidiosis cases. This outbreak was found to be associated with swimming in public pools.[34]

Other documented outbreaks that have been linked to swimming pools include: the skin infection folliculitis (caused by *P. aeruginosa*), respiratory illnesses (caused by *Legionella* and adenovirus), gastroenteritis (caused by *Giardia*, echovirus, norovirus, hepatitis A virus, *E. coli* and *Shigella*), haemolytic-uraemic syndrome caused by *E coli O157* and pharyngo-conjunctivitis caused by adenovirus.

While most of these outbreaks were found to be associated with poor disinfection, some outbreaks occurred in pools that were well maintained because disinfectants need time to inactivate micro-organisms. This time lag is a problem when action is not taken immediately to decontaminate a pool following a potentially infectious accident from faeces or vomit.

2.5 Conclusions

- Outbreaks of disease have frequently been linked to inadequately disinfected pools.
- Only outbreaks involving multiple cases appear to be reported. Many single cases are unreported.
- Even if a swimming pool or spa pool is properly managed and adequately disinfected, disease transmission can still occur by risky or adverse behaviour such as:
  - 'Whale spitting';
  - Faecal accidents and toddlers wearing poorly fitted pants;
  - Poor personal hygiene; and
  - Not toileting and showering before swimming.

- Disinfected swimming pools and spa pools are not sterile and cannot be made sterile.
- Contaminants are being constantly added to the pool by bathers and other sources. Sufficient time is needed for the disinfectant to inactivate the contaminants (depending on the type and concentration) once they enter the pool, e.g. *Cryptosporidium* spp., which may take days.
- It is essential for pool patrons to minimise pool contamination and to avoid risky behaviour.
- Pool operators should never allow disinfectant concentrations to fall below recommended levels and should anticipate high bather loads and raise disinfectant levels in advance.
- There are water treatment processes that may inactivate *Cryptosporidium* more quickly than others, e.g. chlorine dioxide.
- Bathers who have been ill, particularly if they have had diarrhoea in the previous two weeks, should not swim.
- All bathers should be encouraged to use a high standard of personal hygiene before entering a pool.

CHAPTER 3

Microbial criteria and sampling

3.1 Overview

This chapter begins with an explanation of indicator micro-organisms that are used to monitor the microbiological quality of swimming pool and spa pool water. An outline of the microbiological criteria, based on the characteristics of selected indicator micro-organisms, is provided, and the significance of their presence or absence in pool water briefly explained. Based on risk considerations, recommended sampling criteria for the purpose of microbiological testing are provided.

3.2 Indicator micro-organisms

Pathogenic micro-organisms are micro-organisms that are capable of causing disease. Many diseases have been linked to faecal contamination of swimming pool and spa pool water that has not been satisfactorily disinfected. Pathogens may also be released into the pool water from non-faecal sources, such as human skin or secretions, animal pets, rodents and stormwater runoff. They are invariably found in very small numbers, if at all, so testing for these pathogens (viruses, bacteria, protozoans including amoebae or fungi) frequently involves procedures that are complex, very expensive and time consuming. It is impossible to test for some pathogenic micro-organisms because they cannot be easily grown in a laboratory. Routine analysis for these many pathogenic micro-organisms is therefore impractical and inefficient.

Instead, tests are performed for micro-organisms which are expected to be present in water in much greater numbers than individual pathogens, and are therefore easier to enumerate. These are called "indicator" micro-organisms and their traditional role is to primarily indicate the presence or absence of faecal contamination. An ideal indicator micro-organism should possess the following characteristics:

- It should be found in faecally polluted water in large numbers.
- It should not be able to survive and multiply in water.
- It should possess growth and survival characteristics similar to pathogens.
- Isolating, identifying and enumerating these indicators should be relatively easy and inexpensive to perform.

As health risks in pools may be of faecal or non-faecal origin, tests should be performed for both faecally-derived (e.g. *Escherichia coli*) and non-faecally-derived (e.g. *Pseudomonas aeruginosa*) micro-organisms. Faecal indicators are used to monitor possible faecal pollution. Non-faecal indicators are used to monitor microbial growth. Microbiological indicators are a useful tool to determine whether disinfection of pool water, at the time of sampling, was adequate to kill most pathogenic organisms. The presence of any of these micro-organisms indicates a poorly operated disinfection system. Their absence, however, does not guarantee safety, as some pathogens (notably viral and protozoan parasites) are more resistant to treatment than the indicators.

When the results of microbiological testing are received it represents the microbial quality of the water at the time of sampling. Therefore water quality conditions have most likely changed since sampling. It is important that the pool water had been chemically tested at the time of microbiological sample to enable a more meaningful interpretation and correlation.

3.3 Microbiological criteria

The microbiological criteria for a well-managed swimming pool or spa pool are as follows:

Table 3.1: Microbiological criteria

Test	Criterion
Heterotrophic plate count	< 100 cfu / 1 mL of water sample
Escherichia coli (E. coli)	< 1 cfu / 100 mL of water sample
Pseudomonas aeruginosa	< 1 cfu / 100 mL of water sample

cfu = colony forming units mL = millilitre

Microbiological samples should always be collected before chemical samples to avoid accidental contamination of the pool water with micro-organisms from the sampler. Chemical analyses of water for free and total chlorine (or bromine), pH, total alkalinity and temperature should be conducted by the pool side immediately after microbiological sampling. Microbiological tests should only be performed by laboratories accredited by the National Association of Testing Authorities (NATA).

3.3.1 Heterotrophic plate count (HPC)

Heterotrophic plate count is also known by a number of other names, including standard plate count, total plate count, total viable count or aerobic quality count. It does not differentiate between the types of bacteria present nor does it indicate the total number of bacteria present in the water – only those capable of forming visible colonies under specified conditions on certain non-selective microbiological media. Varying the incubation temperature will favour the growth of different groups of bacteria. As it gives more meaningful information about pathogenic (disease-causing) bacteria, 35°C (or 37°C) is the preferred incubation temperature.

HPC does not necessarily indicate microbiological safety as the bacteria isolated may not have been faecally-derived but it does give a measure of the overall general quality of the pool water, and whether the filtration and disinfection systems are operating satisfactorily. Results reported by the laboratory are traditionally expressed as colony forming units per millilitre (cfu/mL) which equates to the number of bacteria in each millilitre of the original sample of water tested. A HPC count of less than1 cfu/mL indicates that the disinfection system is effective. If the count is between 10 and 100 cfu/mL, indicates that a routine investigation should be conducted as soon as possible to ensure that all the management operations are functioning properly. However, counts above100 cfu/mL is indicative of a faulty disinfection system and an urgent investigation should be conducted immediately. The pool water should be re-sampled and sent to the laboratory to be tested again as soon as possible.

3.3.2 *Escherichia coli (E. coli)*

This bacterium is a normal inhabitant of the intestinal tract of warm-blooded animals and is always present in faeces in large numbers (approximately 109/g). *E. coli* is almost exclusively of faecal origin and does not multiply in water. Detection of *E. coli* indicates recent faecal contamination. Results for *E. coli* are normally reported as cfu/100 mL of water tested. Note that the criterion for *E.Coli* is more stringent than HPC because an indication of faecal contamination would mean the likely presence of pathogenic micro-organisms in the pool. It is possible to have high HPC and a low *E. coli* indicating no recent faecal contamination but low overall disinfection efficiency. A high HPC and high *E. coli* indicates a disinfection system that is severely deficient, and bathers would be likely to have been at risk of contracting disease at the time of sampling. *E. coli* is the most reliable indicator of public health risk.

3.3.3 *Pseudomonas aeruginosa*

This is an opportunistic pathogen commonly found in water, soil and vegetation. It also can be found in human and animal faeces. It rarely causes infection in healthy people but can colonise damaged systems, such as burn wounds and damaged eyes. Immunocompromised individuals are particularly at risk. *P. aeruginosa* can grow at the selective temperature of 41-42°C, where most environmental micro-organisms would not survive. This allows it to proliferate to high numbers and cause diseases like ear and eye infections and folliculate skin infections. Although slightly resistant to a range of disinfectants, chlorination of swimming pools should be sufficient to kill the bacterium. However, in environments peculiar to spas such as water turbulence, elevated temperature and high bather loads, considerably greater care is needed to ensure the safe operation of the spa and the eradication of the micro-organism. The bacterium produces a biofilm and may colonise pipes and filter media. Laboratory results for *P. aeruginosa* are normally reported as cfu/100 mL of water tested. It is a more sensitive indicator than *E. coli* and may be detected in their absence. Presence of this micro-organism in the pool indicates that the disinfectant has not been sufficiently maintained continuously at the minimum levels. The pool may need superchlorination, or at least a shock dose of chlorine added upstream to the filter to eliminate biofilm and any micro-organism that may be harbouring in the water and the filter media.

3.4 Microbiological sampling

Ideally, persons collecting samples should be trained and certified competent in the use of aseptic techniques (see below). The following points should be noted concerning sampling:

3.4.1 Sampling technique

"Aseptic technique" should be used at all times during sampling. A part of this technique means that the inside of the container and lid should not be touched otherwise the container is no longer sterile. Sterile containers of 250 to 500 mL capacity containing a trace of sodium thiosulphate (added to neutralise chlorine) should be used. Samples should be collected during periods of maximum bather load. Sampling frequency consistent with Table 3.2 is recommended.

A sampling location close to the pool outlet should be chosen so that it is representative of the water which has already circulated through the pool. The lid from the sterile container should be carefully removed while holding the jar near its base. The lid should not be inverted but held in a mouth down position at all times. The container should be filled in one sweeping movement by plunging the container mouth downwards into the pool and scooping a sample at a depth of at least 450 mm. The mouth of the container should always point ahead of the hand while scooping away from the body. Avoid contamination of the sample by floating debris. The container should not be rinsed to avoid washing out sodium thiosulphate. The top 15 mm of water should be tipped out of the bottle (to allow sufficient headspace for mixing), the lid replaced, and the sample placed in a cooler with sufficient freezer bricks to cool the sample during transport to the laboratory.

3.4.2 Timeliness

Once samples have been collected, it is equally important that they are delivered to the laboratory in a manner that does not alter their condition from that existing at the time of collection. For microbiological samples, it is important that there has been no increase or decline of microbial numbers during transport. Ideally, samples should arrive at the laboratory within six hours, but definitely no longer than 24 hours, after sample collection.

3.4.3 Interpretation

While each criterion has been explained previously, they should not be used as the basis of immediate risk assessment as it could be three days before results are received and inferences made. Results, however, need to be interpreted against the results of chemical testing performed immediately after the microbiological sampling.

3.4.4 Chemical criteria

Each chemical criterion (section 5.2) has been rounded up to give a slight safety margin. Thus, continuous maintenance of a minimum of 1 mg/L of free available chlorine in an outdoor pool (at a pH of 7.5), which is required in the chemical criterion, is slightly more than sufficient than that needed to ensure compliance with the microbiological criteria.

3.4.5 Database

All microbiological sample results should be logged in a database or spreadsheet so that a history of disinfection can be developed. Once patterns have emerged, it may be possible to reduce sample frequency, or other locations can be sampled to enable comparisons.

All three microbiological criterion need to be considered at the one time, from the one sample. The recommended minimum sampling frequencies for the analysis of these indicator micro-organisms are given in Table 3.2. Microbiological criteria is a useful guide to the performance of disinfection in a pool and that it is only an indication of past risk measured as a snapshot at one point in time. Once the snapshots have been placed in a database the whole picture of pool performance begins to emerge so that the pool operator can gain confidence in pool operations and become more competent in pool management.

Table 3.2: Minimum sampling frequency for microbiological analysis

Pool type	Heterotrophic plate count (HPC) < 100 cfu/ mL	*E. coli* < 1 cfu/100 mL	*Pseudomonas aeruginosa* < 1 cfu/100 mL
Category 1 Spas; hydrotherapy pools; pools used by swim schools; pools used by incontinent people; infant wading pools; highest risk pools (see section 3.5)	Monthly	Monthly	Monthly
Category 2 Swimming pools > 26°C (except Category 1 pools); wave, river and low depth (< 1 m) leisure pools; higher risk pools (see section 3.5)	Bi-monthly	Bi-monthly	Bi-monthly
Category 3 Swimming pools < 26°C (except Category 1 and 2 pools); diving pools; low and infrequent bathing load pools	Quarterly	Quarterly	When need arises

Source: Adapted from WHO 2006.

3.5 Micro-organism risk factors

The following risk factors have been associated with microbiological failure of pool water quality. Where three or more risk factors exist in a swimming pool, the pool should be changed to a more stringent category. For example, a Category 3 diving pool should be changed to a Category 2 pool where three or more of the following risk factors are observed:

- pH greater than 7.6 in a chlorinated pool
- Consistently poor disinfection (previous chemical or bacteriological failures)
- High turbidity
- Poor pool circulation or filtration
- High bather loads
- Presence of algae
- Regular use by birds e.g. ducks
- Easy access of foreign material e.g. litter
- Biofilms detected
- Poor quality make-up water (high in chloramines)
- Infrequent testing of disinfectant concentration
- No automatic disinfection and pH control.

When indicator micro-organisms exceed their criterion value, a thorough assessment of the pool's physical and chemical environment should be undertaken. Pool surfaces should be checked for biofilms. Backwashing of the filters may be needed. Concentrations of disinfectant, pH, cyanuric acid, total dissolved solids (TDS) and turbidity should be checked. The incoming water supply should also be checked regularly for chloramines. It may be advisable to engage a consultant.

On most occasions microbial failure is due to inadequate continuous disinfection. Failures may also occur as a result of high turbidity and biofilms, which can shield micro-organisms from disinfectants. Biofilms within pipes and filtration units may harbour micro-organisms especially in pools that are not continuously held above the minimum disinfection levels or in the proper pH range. Regularly super-chlorination or oxidant shocking may be needed to destroy biofilms.

Following rectification of any pool problems, the pool water should be re-sampled to confirm that the swimming pool or spa pool is safe for use.

CHAPTER 4

Disinfection

4.1 Overview

Chapter 2 explained that micro-organisms can be transmitted from bather to bather directly in swimming pool water. It is impossible to prevent pathogenic micro-organisms from entering the pool, particularly from bathers. It is therefore essential that a residual disinfectant be present in the pool at all times and in sufficient strength to inactivate or kill the pathogenic micro-organisms as soon as possible.

Disinfectants take time to inactivate micro-organisms, and while they do not eliminate the risk of disease entirely, disinfection significantly reduces the risk of disease transmission. It is important to understand how disinfectants work and the factors that enhance or impede their ability to kill micro-organisms.

This chapter considers disinfectant properties in general, and specifically the halogen disinfectants of chlorine and bromine. Disinfection systems which are not primarily based on chlorine or bromine are not accepted in NSW.

Swimming pool and spa pool chemical parameters are included in Chapter 5.

4.2 Disinfectant properties

There is no perfect disinfectant. An ideal disinfectant however, would have the following properties:

- **Residual:** The disinfectant needs to remain active in the body of pool water. For example, ultra violet (UV) light does not impart any residual effect to the pool water while chlorine and bromine do. A good disinfectant does not dissipate quickly but slowly decreases as it disinfects.
- **Oxidiser:** It is important that there is an oxidising effect in the pool to oxidise organic matter, particularly inorganic nitrogen compounds. These impurities are responsible for algal growth, reducing the effectiveness of chlorine disinfection, are irritants and are pollutants.
- **Efficiency:** The disinfectant needs to be wide spectrum and rapid in its action so that there is not enough time for the diverse types of micro-organisms to transmit through the pool.
- **Measurable:** The concentration of the disinfectant needs to be measurable at the pool side using an easy and accurate test methodology to enable rapid corrective action.
- **Economic:** The disinfectant needs to be cost effective.
- **Dosing:** The disinfectant needs to be in a form that is easy to dose automatically in a pool. A liquid is the easiest and safest form to use. Devices to dose both solids and powders are now available.
- **Safety:** The disinfectant needs to be relatively safe to handle. It should not be flammable, explosive or toxic in a gaseous form. It should be easy to transport and to contain spillages. The disinfectant should not generate fine dust or respirable particles.
- **Side effects:** The disinfectant should have the least unwanted side effects.

The halogens of chlorine and bromine are the most popular because of their known properties, proven effectiveness, ease of use and being cost effective when used properly with automated equipment. While neither disinfectant is perfect, each has its relative advantages and disadvantages. The APVMA guide previously mentioned in Section 1.6, "Guide to demonstrating efficacy of pool and spa sanitisers" is a guide for establishing the efficacy of new sanitisers apart from chlorine and bromine sanitisers.

4.3 Disinfection concepts

Pool operators need to be aware of some basic concepts of disinfection.

- **Logarithms:** In the following logarithmic scale:
  1 Log = 10; 2 Log = 100; 3 Log = 1000; 4 Log = 10000
  each increased log number equals an additional "0" or multiplication by 10. Therefore a 1 Log reduction means the same as removing a "0" or a reduction by 90%, since a 90% reduction is the same as dividing by 10. A 2 Log reduction means the same as a 99%

reduction since a 99% reduction is the same as dividing by 100, and so on.

- **Percentage kill:** A swimming pool can be easily faecally contaminated with 1 gram of faeces (1 gram of faeces is about the size of a small pill and can contain well over 1 million (or 1 x 106 in scientific notation) pathogenic bacteria. A 90% kill (or 1 Log kill) inactivates 900 000 and still leaves about 100 000 bacteria. A 99% kill rate (2 Log kill) leaves 10 000 bacteria, and so on. A kill rate of 99.9% seems good but the 1000 bacteria remaining can still cause an infection and if the disinfectant is exhausted during the disinfection process then the bacteria may regrow under the right conditions. Disinfection should aim for at least a 4 Log (99.99%) reduction and preferably a 5 Log (99.999%) reduction.
- **Kill time:** Ideally an effective disinfectant should cause a 99.99% (4 Log) reduction in bacteria in about 60 seconds or less. This is achievable by 1 mg/L of free chlorine at a pH of 7.5 in an outdoor pool for many micro-organisms. However, bacteria protected by biofilm, spores or encapsulated in organic matter will take longer to kill.
- **Bacteriostatic:** This term means that the micro-organisms are prevented from multiplying, their numbers are held static, and they die from natural attrition processes but not as a result of chemical disinfection. **Bactericidal** means that the chemical kills or inactivates the micro-organism.
- **Oxidising:** It is an advantage if the disinfectant also oxidises or breaks down organic matter particularly nitrogen-containing compounds which would encourage the growth of algae. Periodic addition an oxidising chemical such as hydrogen peroxide or potassium monopersulphate may enhance the disinfection capacity of chlorine or bromine after heavy bathing loads.
- **Ct value:** Studies have been undertaken to assess the effectiveness of various disinfectants. The effectiveness of a disinfectant can be expressed by its Ct value. This is the concentration (C) of the disinfectant (expressed in mg/L) multiplied by the time (t, expressed in minutes) required to give a certain log reduction (inactivation) of micro-organisms. It is recommended that a free chlorine Ct value of 15 300 mg-min/L is required to achieve 3 Log inactivation of *Cryptosporidium parvum* spores. For example, to achieve a Ct value of 15 300 using a chlorine concentration of 15 mg/L then:

  Ct = 15 300 = 15 mg/L (C) x time (t)
  Therefore Time (t) = 15 300 ÷ 15 = 1020 minutes or 17 hours

- **Temperature:** As temperature increases, the growth rate of micro-organisms also increases until an optimum growth temperature is reached. After the optimum growth temperature is reached the micro-organism does not grow as quickly. It has been found that *Pseudomonas aeruginosa* cannot be sufficiently controlled by 1 mg/L of free chlorine at temperatures greater than 26°C. Heated indoor swimming pools and spa pools therefore need a higher concentration of free chlorine to control this micro-organism.

4.4 Characteristics of various disinfectants

4.4.1 Chlorine-based disinfectants that produce hypochlorous acid

Chlorination is the most commonly used swimming pool disinfection technique and is available in the compounds below in Table 4.1 Common Chlorine Compounds (although chlorine gas is rarely used).

Table 4.1: Common Chlorine Compounds

	Sodium hypochlorite	Calcium hypochlorite	Lithium hypochlorite	Chlorine gas	Trichloro isocyanurate	Dichloro isocyanurate
% Available Chlorine	10-12	65-78	35	100	90	50-63
% Active Strength	10-12	65-78	29	100	>99	>99
pH in 1% solution	13	8.5-11	10.8	0	2.8-3.5	6.5-6.8
pH effect in water	Raises	Raises	Raises	Lowers	Lowers	Neutral
Physical appearance	Liquid	Granular Tablet Briquette	Granular	Yellow green gas	Granular Tablet	Granular

(Source: USA National Swimming Pool Foundation)

When a hypochlorite compound e.g. sodium hypochlorite or calcium hypochlorite, is added to water, hypochlorous acid (HOCl) is formed. Hypochlorous acid partially dissociates (splits apart) in water in equilibrium with H^+ (hydrogen ion) and OCl^- (hypochlorite ion), as shown in the following chemical reaction:

HOCl		**H^+**		**OCl^-**
Hypochlorous acid (Strong disinfectant)	⇆	Hydrogen ion	+	Hypochlorite ion (Weak disinfectant)

This is a chemical equation that uses a dissociation sign (⇆) because the chemical equation can react in either direction depending on conditions in the water environment. It uses the dissociation sign because the equation is always trying to reach equilibrium or a balance between the concentrations of hypochlorous acid (HOCl), the hydrogen ion (H^+) and the OCl^- (hypochlorite ion). The balanced proportion can vary with pH changes. When pool water becomes more acidic (towards pH 7), the hydrogen ion concentration increases, combines with the hypochlorite ion and drives the equation to the left to form more hypochlorous acid. When pool water becomes more alkaline (towards pH 8) the hydrogen ion concentration decreases. To make up for the shortage H^+ splits from the HOCl and drives the equation to the right to also form OCl^-. The concentration of HOCL will therefore decrease. This effect will be explored further when considering the effect of pH on the disinfection power of free chlorine.

(i) Free available chlorine (free chlorine)

Free available chlorine (also called free chlorine or FAC) is a measure of the concentration of hypochlorous acid plus the concentration of the hypochlorite ion expressed in milligrams per litre (mg/L). The reagent used to measure free chlorine is diethyl-p-phenylene diamine (DPD) commonly known as DPD Tablet No. 1. When a DPD No. 1 tablet is dissolved into a 10 mL sample of pool water a deep pink/purple coloured solution will develop depending on the concentration of free chlorine present.

Hypochlorous acid (HOCl) is the active disinfecting component of free chlorine. The hypochlorite ion (OCl^-) is not effective as a disinfecting component of free chlorine. It is logical to maximise hypochlorous acid and to minimise the hypochlorite ion because this affects the potency of free chlorine as a disinfectant. This aspect of disinfection will be discussed more in the next section.

(ii) The effect of pH on chlorine disinfection power

Hypochlorous acid (HOCl) is a powerful disinfectant and the hypochlorite ion (OCl^-) is a weak disinfectant. The disinfection power of free chlorine is the opposite to the pH of the pool water; as pH increases then free chlorine disinfection power decreases. Table 4.2 shows how the percentage concentration of hypochlorous acid in free chlorine decreases with increasing pH because the hypochlorous acid converts to the hypochlorite ion. Free chlorine at pH 7.5 is only half as powerful as at pH 6.0. Above pH 7.8, free chlorine has lost most of its disinfection power.

Table 4.2: Percentage of hypochlorous acid determined by pH:

pH	Percentage Disinfection Power of Hypochlorous acid (HOCl) as Free Chlorine
6.0	97
7.0	75
7.2	63
7.5	49
7.6	39
7.8	28
8.0	3

Because the relationship between HOCl and OCl^- is pH dependent, a higher concentration of hypochlorous acid must therefore be maintained when the pH exceeds 7.6 to maintain overall disinfection power. Preferably, pH should be maintained between 7.2-7.6 because more hypochlorous acid is available for disinfection. If pH rises above 7.6 then free chlorine must be increased by an additional 1.0 mg/L to compensate for the loss of HOCl potency. pH must never rise above 7.8 in a chlorine disinfection system because of the significant loss of disinfection power.

Regularly monitored and maintained automatic control systems are capable of maintaining pH and free chlorine within acceptable disinfection limits. Automatic control is considered essential best practice for all public swimming pools and spa pools.

(iii) Total chlorine, free chlorine and combined chlorine

As mentioned, free chlorine is determined using DPD No. 1 tablet. Total chlorine is a measure of all of the chlorine compounds which may be found in a pool. Also measured in mg/L, it is determined by adding a DPD No. 3 tablet to the free chlorine water sample and after two minutes, the purple colour represents the total chlorine concentration. The relationship between total chlorine, free chlorine and combined chlorine is as follows:

Free Chlorine (DPD 1) + Combined Chlorine = Total Chlorine (DPD 1+3)

Therefore the difference between Total Chlorine (DPD 1+3) and Free Chlorine (DPD1) is combined chlorine or:

Total Chlorine (DPD 1+3) – Free Chlorine (DPD 1) = Combined Chlorine

Combined chlorine is also called chloramines and is a measure of the chlorine that has combined with various forms of nitrogen compounds, particularly ammonia. Chloramines can be either inorganic or organic.

Chloramine compounds cause skin irritation, eye irritation, corrosion, and a strong and offensive chlorine odour that can be sometimes smelled when entering a swimming pool area. Chloramine compounds are very poor disinfectants (about 60 to 100 times less effective than hypochlorous acid). It is essential to eradicate or at least minimise chloramines.

(iv) Bather pollution and the formation of chloramines

Combined chlorines are formed when chlorine combines with other compounds. In a swimming pool chlorine mainly combines with compounds that enter the pool from bather contamination. As these contaminating compounds breakdown they form two types of chloramines:

- *Inorganic chloramines:* Chlorine reacts with ammonia mainly derived from human excretions. The ammonia comes from the breakdown of urea, creatinine, uric acid, glycine, histidine, arginine and other compounds from urine and to a lesser extent from perspiration. Ammonia reacts with chlorine to form chloramines (monochloramine, dichloramine and trichloramine). Ammonia may also be introduced from a water supply which has been disinfected using chloramination techniques. Chloramines severely reduce disinfection efficiency and may cause harm to bathers. The following equations show the chloramine compound formation reactions:

Formation of monochloramine from ammonia

$HOCl$	+ NH_3	→ NH_2Cl	+ H_2O
Hypochlorous acid	Ammonia	Monochloramine	Water

Formation of dichloramine from monochloramine

$HOCl$	+ NH_2Cl	→ $NHCl_2$	+ H_2O
Hypochlorous acid	Monochloramine	Dichloramine	Water

Formation of trichloramine from dichloramine

$HOCl$	+ $NHCl_2$	→ $NHCl_3$	+ H_2O
Hypochlorous acid	Dichloramine	Trichloramine	Water

  Nitrogen gas, nitrate and other by-products form from these reactions in varying proportions depending upon pH, temperature, contact time and the ratios of chlorine to ammonia and chlorine to ammonia nitrogen concentrations.

  Trichloramine is more prone to formation at relatively low pool pH of 7. Trichloramine, and to a lesser extent dichloramine, cause severe irritations to the skin, eyes and respiratory tract. Trichloramine is the most volatile chloramine and is responsible for the strong chlorine-like odour associated with poorly maintained indoor swimming pools and spa pools. This problem should not arise in properly managed outdoor aquatic centres.

  Inorganic chloramines tend to persist in indoor pools for hours until oxidised. Chloramines are volatile and are slowly given off from pool water. If there is insufficient ventilation or if pool blankets are used during overnight chlorination then the chloramines might not be able to dissipate and may be reabsorbed into the pool water. Volatile chloramines will also cause corrosion to fabrics and fittings.

- *Organic chloramines*. Organic chloramines are formed when chlorine combines directly with the organic molecules of urea, creatinine, uric acid, glycine, histidine, arginine and other compounds from urine and to a lesser extent from perspiration. Organic chloramines are very persistent and it may be many days before they are broken down. Organic chloramines also adversely affect disinfection rates, cause eye stinging and cause odours. It is essential that people not urinate in the pool and the practice should be actively discouraged.

(v) Reducing chloramines

Breakpoint chlorination and superchlorination are common techniques used to control inorganic combined chlorine. Breakpoint chlorination and superchlorination do not control organic combined chlorine. A detailed explanation may be found in Appendix A.

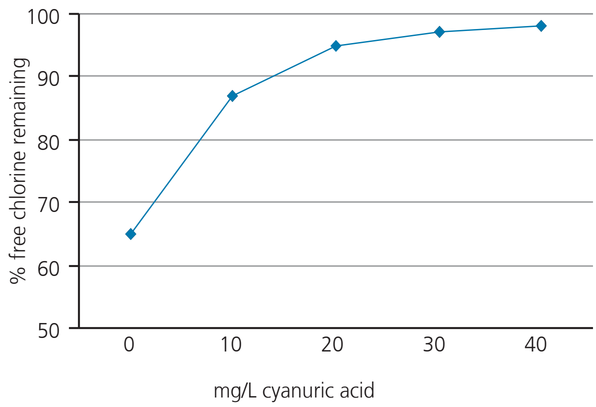
Other techniques may need to be employed to reduce organic chloramines that use non-chlorine oxidisers such as hydrogen peroxide, ozone, medium pressure UV light lamps and potassium monopersulphate. The use of these chemicals is also known as "oxy shocking" and in some indoor pools may need to be practiced once a week. Oxy shocking may interfere temporarily (perhaps overnight) with total chlorine measurement and ORP controllers. These techniques are also effective against inorganic chloramines. The use of oxy shock chemicals and UV light assist the disinfection power of free chlorine by reducing chlorine demand to perform oxidation. Generally oxidisers are poor disinfectants but are better oxidisers than free chlorine. Competent professional swimming pool consultants should be engaged when considering these chloramine-reducing techniques.

(vi) Stabilised chlorine – cyanurate products and cyanuric acid

When UV light from the sun shines on a swimming pool it converts hypochlorous acid (HOCl) to hydrochloric acid (HCl) which has no disinfection power. The conversion of hypochlorous acid by UV light from the sun therefore gradually decreases the disinfection capacity of the pool water. Even more chlorine then has to be added to the pool to maintain minimum disinfection levels.

Cyanuric acid (cyanurate) is a chemical which, when added to pool water, forms a weak bond with hypochlorous acid. It stabilises hypochlorous acid to reduce losses from the pool caused by UV light from the sun. Some of the hypochlorite ion converts to hypochlorite to compensate for some of the loss of hypochlorous acid. Testing has shown that pool water without cyanuric acid, when exposed to the sun, loses approximately 35% of the free chlorine each hour (Graph 4.1). As the concentration of cyanuric acid rises in a swimming pool, less proportionately free chlorine is lost from the pool. Above 20 mg/L of cyanuric acid, the law of diminishing return applies where there is very little extra loss of free chlorine with the addition of more cyanuric acid. On a sunny day, outdoor pools without cyanuric acid may lose up to 90% of the free chlorine residual over the whole day, compared with only a 15% loss when cyanuric acid was used.

Graph 4.1: Cyanuric acid concentration vs percentage free chlorine loss in one hour



There is no benefit using cyanuric acid in an indoor pool because the pool water is not exposed to direct UV light, even if the pool is covered with Perspex® or glass little UV light is transmitted.

Unfortunately, the addition of cyanuric acid also reduces the disinfection power of hypochlorous acid because of the weak bonds formed between these compounds. A 50 mg/L concentration of cyanuric acid may increase the time needed for a 4 Log reduction of *Pseudomonas aeruginosa* from 1 minute to approximately 5 minutes. It is therefore necessary to operate an outdoor pool at 3 mg/L free chlorine when using cyanuric acid. Cyanuric acid greatly reduces the power of free chlorine to disinfect *Cryptosporidium* oocysts. Further studies using oxidation-reduction potential (ORP – see section 8.3.1), have shown a loss of ORP when cyanuric acid has been added to swimming pool water. A significant loss of disinfection power is commonly called chlorine lock and is the subject of some debate among pool professionals and chemical companies.

Cyanuric acid is only lost from the pool through backwashing and splashing and only diluted by the addition of water so it only needs to be added occasionally, but not continuously. It is best practice to add cyanuric acid until the maximum concentration in the pool is 50 mg/L. The concentration gradually drops over weeks until it reaches 20 mg/L. The pool should then be dosed again to 50 mg/L.

Where a chlorinated cyanurate compounds, such as tri- or dichloroisocyanurate are used to chlorinate a pool, it must be discontinued when the cyanuric acid concentration exceeds 50 mg/L and another form of chlorine used. If cyanurate concentration exceeds the maximum concentration of 50 mg/L the disinfection rate is too slow and diseases could be more readily transmitted. The optimal concentration of cyanuric acid is 30 mg/L. The continuous use of chlorinated cyanurate compounds is discouraged otherwise a very high cyanuric acid level can be reached which greatly impede disinfection rates.

In summary, while cyanurate bonds to free chlorine to reduce losses of free chlorine in sunlight it also reduces the disinfection effect. Increasing the free chlorine concentration in an outdoor pool from 1 mg/L to 3 mg/L compensates for this loss of disinfection effect. The overall result is a net saving in the use of chlorine disinfectant and a monetary saving to the pool operator.

(vii) Electrolytic generation of hypochlorous acid

There are two methods of on-site electrolytic generation of hypochlorous acid:

i) In line salt-water generation,
ii) Brine solution generation.

Both methods employ electrodes immersed in salt water. Electrolytic generation does not need to be registered with the APVMA (see section 1.5) as a disinfectant because it is an on-site generation process.

In line salt-water generation is commonly known as salt-water chlorination. A common salt (NaCl) concentration of approximately 3000 mg/L is maintained in the swimming pool. Circulating pool water passes through a coarse filter, a pump, a filter and a heat exchanger, if fitted, and then through an electrolytic cell containing a cathode and anode, before being returned to the pool inlets. The cell may be located on a side stream to the circulation system. This system operates only while the circulation system operates. Chlorine gas is generated at the anode while hydrogen gas is generated at the cathode. The chlorine gas rapidly dissolves into the pool water leaving no gas residue while the hydrogen gas is vented directly to the atmosphere. The system uses DC electricity that periodically reverses polarity to reduce scale formation on the electrodes. The chlorine gas immediately dissolves to form hypochlorous acid and the pool operates according to normal chlorine chemistry. It appears that the high level of hypochlorous acid generated in the electrolytic cell may oxidise chloramines in the cell and in the return line to the pool thus constantly reducing chloramine concentration. Salt is lost from the system by backwashing and splashing and salt needs to be infrequently added to the pool. This system is more suited to smaller pools as it is limited in the amount of free chlorine that can be produced. Generally, additional chlorine can only be introduced by operating the system for a longer time or installing additional cells that come on-line when chlorine demand is high.

Brine solution generation uses a separate container of brine (salt water) for generation. Brine is produced in a tank to the required strength using softened water and common salt. Common salt also contains bromine. The brine is passed through the electrolytic cell, as outlined above, which generates hypochlorous acid and hypobromous acid for storage in a day cell at a concentration of about 8000 mg/L (0.8 % solution). The swimming pool is automatically dosed from the day tank. A low level switch in the day tank activates the production of more hypochlorous acid. Apparently mixed oxidants are also produced, in addition to free chlorine, which leads to the destruction of chloramines. The mixed oxidants may interfere with total chlorine measurement resulting in a false high result for combined chlorine.

4.4.2 Bromine-based disinfectants

The use of bromine disinfectants became popular during World War II when chlorine was scarce. Bromine is mainly used in heated spas as it is more stable than chlorine at higher temperatures. Bromine is less suitable for outdoor pool use because it cannot be stabilised against losses due to UV light and is more expensive than chlorine-based disinfectants. However, in a mixed system (see sodium bromide systems below) where the bromine is activated by chlorine or ozone it may be cheaper than adding chlorine alone.

Bromine belongs to the halogen elemental group in the period table of elements, which consists of fluorine, chlorine, bromine, iodine and astatine. Bromine is a larger atom than chlorine and its compounds disinfection rate is slower than those of chlorine. While bromine chemistry is similar to chlorine chemistry, hypobromus acid (HOBr) has about half the disinfection efficacy or potency of hypochlorous acid (HOCl). Similarly, hypobromus acid is not as strong an oxidiser as hypochlorous acid.

Bromine is used to disinfect swimming pool and spas by two different mechanisms:

***Bromo-chloro-dimethylhydantoin* (BCDMH)** is the most common bromine-based swimming pool disinfectant. BCDMH is known to cause skin and eye irritations. However irritations are less likely to occur in properly maintained pools where water balance and adequate dilution prevent a build-up of disinfection by-products and other chemicals.

Dimethylhydantoin (DMH) is a disinfection by-product of BCDMH, which has been associated with skin irritation (bromine itch) when the DMH concentration in pool water becomes too high. Pool operators need to maintain DMH below 200 mg/L. This is achieved by frequent backwashing and dilution with fresh water. Heavily used spa pools within high-risk premises (such as nursing homes) should be emptied and cleaned weekly. Spa pools which are infrequently used and well maintained are likely to maintain good water quality and therefore could be emptied less frequently (maximum three months).

Sodium bromide (NaBr) systems, also known as bromine bank systems, use an oxidising activator (hypochlorite, ozone or potassium monopersulphate) to generate hypobromous acid to disinfect swimming pool and spa pool water. It is important to maintain an excess of sodium bromide at all times and the amount of activator cannot exceed the sodium bromide. This ensures that excess activator such as ozone is not generated and released (de-gassed) from the pool. The controllers used for chlorine control can also be used for bromine control. Generally, such systems generate less volatile chloramines than chlorine alone.

Systems using ozone to re-generate bromine require skilled designers and trained operators to ensure system performance, safety and healthy conditions. The operator needs to ensure that the correct disinfection concentration is maintained as well as ensuring the prevention of ozone de-gassing and safe levels of bromate. Bromide ions react with ozone to form free bromine. Hence, the prevention of ozone contamination and the maintenance of adequate bromine for disinfection depend on a continual supply of bromide ions, which needs to be carefully monitored and controlled.

(i) The hydrolysis of bromine to form hypobromous acid

Similar to chlorine, bromine in water hydrolyses to form hypobromous acid. Hypobromous acid also dissociates in water to form the hypobromite ion as follows:

HOBR	⇆ H+	+ OBr⁻
Hypobromous acid	Hydrogen Ion	Hypobromite Ion

Unlike free chlorine, the DPD No 1 tablet measures the concentrations of hypobromous acid, the hypobromite ion as well as bromamines. Therefore the DPD tablet No. 1 effectively measures total bromine. If using chlorine measuring methodology, the free chlorine result should be multiplied by 2.25 to obtain the equivalent total bromine concentration.

(ii) The formation of bromamines

Like chlorine, bromine reacts with ammonia to form bromamines, all of which have similar disinfection properties to bromine, unlike chloramines. Nitrogen tribromide also forms in bromine treated pools, which can cause irritations to the eyes and respiratory tract .36 Unlike trichloramine, tribromamine does not produce offensive odours.

(iii) The effect of pH on bromine disinfection power

Table 4.3: Percentage of hypobromous acid in free bromine determined by pH

pH	Percentage of free bromine as	
	Hypobromous acid (HOBr)	Hypobromite ion (OBr^-)
6.0	100	0
7.0	98	2
7.2	96	4
7.5	94	6
7.6	91	9
7.8	87	13
8.0	83	17

Similar to chlorine, the hypobromite ion is a poor disinfectant, and its formation is pH dependent similar to the hypochlorite ion. However, the disinfection power of free bromine does not decrease significantly when the pH of the water is raised whereas free chlorine would. Additional bromine is therefore not required at elevated pH levels above 7.6. Compare Table 4.2 to Table 4.3.

(iv) Isocyanuric acid and bromine

Isocyanurate has no stabilising effect on bromine against the action of UV light unlike with chlorine. Isocyanurate is therefore of no use in outdoor bromine treated swimming pools.

(v) Breakpoint bromination and super-bromination

Because oxidisers more rapidly oxidise bromamines than chloramines, breakpoint bromination techniques are not as significant in swimming pool operation. To inactivate *Cryptosporidium* oocysts, and to remove resistant biofilms and nitrogen compounds, bromine-treated pools still need to be shock-dosed with chlorine (WHO 2006) or with a non-halogen based oxidiser such as hydrogen peroxide or potassium monopersulphate, but not ozone. Care must be taken to ensure that bromates are not produced. Excessively high bromine concentrations can cause pools to turn green or black.

4.4.3 Chlorine dioxide

Chlorine dioxide (ClO_2) is an unstable gas at room temperature. It is heavier than air and readily dissolves in water. ClO_2 is not a strong oxidiser but it is a powerful disinfectant. ClO_2 is particularly efficacious against *Cryptosporidium* and *Giardia* being up to 32 times more effective than hypochlorous acid. The Ct value of ClO_2 is 78 mg-min/L while the Ct value for free chlorine is 15 300 mg-min/L. ClO_2 does not oxidise ammonia to form amines. It does not cause odours.

ClO_2 cannot be stored and transported because it is explosive and must be generated on site. ClO_2 may be generated electrochemically, from tablets or from a liquid stabilised chlorine dioxide chemical in the chlorite form. The liquid form must be activated by dilution and acidification to pH 2. ClO_2 is a more expensive disinfectant than chlorine or bromine. The activator contains a small quantity of cyanuric acid but it is not in sufficient quantity to be considered to be a stabiliser for the purposes of clause 11 of Schedule 1 of the *Public Health Regulation 2012.*

ClO_2 is measured using a modified DPD tablet using glycine as an additional reagent. Otherwise it is impossible to distinguish from other forms of chlorine particularly hypochlorous acid. ClO_2 generates chlorite, which is harmful to human health and should not exceed 0.3 mg/L, a concentration derived from the National Drinking Water Guidelines. Such a scenario is more likely with permanent use of ClO_2 on its own but greatly reduced when ClO_2 is used as an adjunct to hypochlorite-based disinfection.

The ideal use of ClO_2 appears to be in the periodic control of *Cryptosporidium* and *Giardia* particularly in conjunction with chlorine pools where its action is enhanced. During periodic control, the pool needs to be closed for a shorter period than is required if hypochlorous acid is used on its own. ClO_2 is also effective in controlling biofilms by oxidising the polysaccharide matrix.

4.5 Other disinfection systems

There are a number of APVMA approved disinfection treatment chemicals and systems for use in swimming pools and spa pools. Table 4.4 lists satisfactory disinfectant systems based on either chlorine or bromine. Also listed are disinfectant systems considered unsatisfactory when used without chlorine or bromine. Polyhexanide is only considered suitable for lightly loaded domestic pools.

Table 4.4: Satisfactory and unsatisfactory disinfectant systems for public swimming pools and spa pools

Satisfactory disinfectant	Unsatisfactory disinfectant
Chlorine	Ultra violet light without chlorine or bromine
Isocyanurated chlorine in outdoor pools – temporary use	Ozone without chlorine or bromine
Bromine (indoor use)	Silver/copper without chlorine or bromine
Chlorine/bromine systems	Hydrogen peroxide
Ozone with chlorine	Magnetism
Ozone with bromine	Iodine
Ultra violet light with chlorine	Products containing polyhexanide *

* Polyhexanide is used to disinfect some domestic swimming pools. Chlorine should not be mixed with Polyhexanide as a red precipitate may form.

While chlorine and bromine are the recognised primary disinfectant systems in NSW, there are no objections to the use of adjuncts such as oxidisers, copper/silver ionisation, UV light and ozone. Such adjuncts are viewed as treatment methods that may assist chlorination or bromination but are not recognised as disinfectant systems on their own.

4.6 Disinfection by-products (DPBs)

Disinfection by-products (DPBs) are unwanted chemical compounds that may form during the disinfection process and that have suspected health implications such as triggering asthma attacks and certain cancers. Some of these chemicals such as the trihalomethanes (THMs), chlorate, chlorite and bromate can cause health problems that may develop after many years of exposure. Studies however, have indicated that THMs in swimming pools are below drinking water standards and pose little risk in well maintained pools.

The most notable indicator of possible DPB formation is total organic carbon (TOC) which should be maintained as low as possible in swimming pool water prior to disinfection. TOCs are introduced through most swimming pool contaminants particularly urine, perspiration and cosmetics. While perspiration is difficult to control, urine and cosmetics can be minimised.

The microbiological control of swimming pool water should be maintained while minimising the formation of DPBs. The health risks associated with DPBs are very small compared to the health risks of waterborne diseases. Waterborne diseases present an acute risk from immediate exposure.

In properly managed pools evidence suggests that the low concentration of disinfection by-products should not pose a risk to public health (WHO 2006).

CHAPTER 5

Disinfection chemical criteria, other chemicals, sampling and monitoring

5.1 Overview

Disinfection of swimming pool and spa pool water is essential for protecting public health. Monitoring of swimming pool and spa pool water quality ensures that the water quality is maintained. It is necessary that an evidence-based chemical disinfection criterion be available to ensure that disinfection is effective. The disinfection chemical criteria are evidence based. It therefore provides confidence of adequate disinfection protection in all but exceptional circumstances of faecal and vomit contamination and contamination by *Cryptosporidium* and *Giardia* (see Chapter 8).

5.2 Chemical criteria

There are two primary disinfection paradigms acceptable and they are based on the halogens of chlorine and bromine. Other chemicals or systems, such as ozone or UV light, may be used in conjunction with chlorine or bromine. Schedule 1 of the *Public Health Regulation 2012* should be consulted as the prescribed operating requirements for public swimming pools and spa pools.

5.2.1 Dosing

It is best practice that automatic dosing equipment either utilising amperometric or oxidation-reduction potential technology is installed at all public pools and spas. Such equipment should control both the disinfectant and pH. It is recommended that data-logging technology also be used.

It is mandatory that at least, continuous disinfectant dosing equipment be installed (See Section 6.3). It is best practice to install automatic dosing equipment.

Continuous dosing equipment is where the disinfectant addition can be set at a predetermined rate to introduce the disinfectant into the circulation system and mixed prior to the water re-entering the pool. Automatic dosing refers to a dosing system dependent on a disinfectant sensory and feedback system to determine the dosing rate and adjusting the dosing equipment accordingly.

Slug, hand dosing or broadcasting may only be used for special chemical applications, such as isocyanuric acid or dry acid, and only at a time when the pool is closed to patrons. The pool should not be opened to the public until the chemical reactions have been completed and this may take some hours or overnight.

5.2.2 Chlorine systems chemical criteria

The following Table 5.1 is a summary of the prescribed operating requirements of Schedule 1, *Public Health Regulation 2012* (see 1.5) for chlorine based disinfection of public swimming pools and spa pools. Schedule 1 should be consulted as the primary source of information and takes precedence over Table 5.1.

5.2.3 Bromine systems chemical criteria

The following Table 5.2 is a summary of the prescribed operating requirements of Schedule 1, *Public Health Regulation 2012* for bromine based disinfection of public swimming pools and spa pools. Schedule 1 should be consulted as the primary source of information and takes precedence over Table 5.2.

Table 5.1: Chemical criteria for chlorine-based pools

Parameter	Situation	Concentration
Free Available Chlorine (1) (DPD No 1)	Outdoor Pool	Min 1.0 mg/L
	Outdoor Pool + Cyanuric Acid	Min 3.0 mg/L
	Indoor Pool	Min 2.0 mg/L
	Spa Pool	Min 2.0 mg/L
	Any pool where pH > 7.6	Raise min by 1.0 mg/L
Oxidation Reduction Potential (ORP)(4)	ORP automation	Min 720 mV
Combined Chlorine (3)	Any pool	Max 1.0 mg/L
Total Chlorine (DPD No 1 + No 3)	Any pool	Max 10.0 mg/L
pH	Any pool	Range 7.0 to 7.8
Total Alkalinity	Any pool	80 to 200 mg/L
Cyanuric Acid	Outdoor pool only. Not spas	Max 50 mg/L
Ozone (2)	Any pool	Zero

(1) **Free Available Chlorine** concentration should be increased when high bather loads are anticipated to ensure that concentrations are never less than the minimum. Super-chlorination should only be carried out when the pool is closed.

(2) Residual excess **ozone** is to be quenched in an activated carbon filter bed before the circulated water is returned to the pool. The contact time between the pool water and the ozone should be at least 2 minutes at an ozone concentration of 1 mg/L where injected before filtration, and at least 0.8 mg/L where injected after filtration. Where ozone is generated at the rate of less than 2mg/hour quenching should not be required where the ozone is introduced into the circulation system by a venturi and completely dissolved in the pool water.

(3) Some oxidants may interfere with reagents used to measure **combined chlorine**. Interference must be demonstrated by the pool operator to allow exemption from the combined chlorine maximum.

(4) Where **Oxidation Reduction Potential** (ORP) measuring equipment or automatic dosing equipment is installed, the ORP should be set to the equivalence of the minimum free chlorine concentration and shall be not less than 720mV.

Table 5.2: Chemical criteria for bromine-based pools

Parameter	Situation	Concentration
Bromine (1) (DPD No 1)	Outdoor Pool	Min 2.25 mg/L
	Indoor Pool	Min 4.5 mg/L
	Spa Pool	Min 4.5 mg/L
Bromine	Any Pool	Max 9.0 mg/L
pH	Any pool	7.0 to 8.0
Sodium Bromide (NaBr)	Bromine Bank System	Max 9.0 mg/L
Sodium Bromide (NaBr)	Ozone (2) / Br System	Max 15 mg/L
Total Alkalinity	Any pool	80 to 200 mg/L
Di-methylhydantoin	Any pool	Max 200 mg/L
Cyanuric Acid	Any pool	None – no benefit
ORP (3)	Any pool	700 mV

(1) **Bromine** concentration should be increased when high bather loads are anticipated to ensure that values are never less than the minimum. Super-chlorination should only be carried out when the pool is closed.

(2) **Ozone** quenching is not required in the Ozone / Bromide system. In other systems residual excess ozone is to be quenched in an activated carbon filter bed before the circulated water is returned to the pool. The contact time between the pool water and the ozone should be at least 2 minutes at an ozone concentration of 1 mg/L where injected before filtration, and at least 0.8 mg/L where injected after filtration. Where ozone is generated at the rate of less than 2mg/hour quenching should not be required where the ozone is introduced into the circulation system by a venturi and completely dissolved in the pool water.

(3) Where **Oxidation Reduction Potential** (ORP) measuring equipment or automatic dosing equipment is installed, the ORP should be set to the equivalence of the minimum bromine (DPD #1) concentration and shall be not less than 700mV.

5.2.4 Alternate disinfection systems

No other disinfectant system, apart from chlorine or bromine based systems may be used on their own. Stand alone UV light/hydrogen peroxide systems and copper/silver ionic systems are not acceptable in NSW.

5.2.5 Oxidation-reduction potential

Where oxidation-reduction potential (ORP) measuring equipment or automatic dosing equipment is installed, the ORP should be set to the equivalence of the minimum free chlorine concentration at a pH of 7.2 and shall not be less than 720 mV and 700 mV for bromine (see Section 6.3).

5.2.6 Pool operating periods

Swimming pools and spa pools need to be operated for a period of time after closure to the public without additional bather contamination to recover and to achieve breakpoint chlorination. This period of time can only be determined by the experience of the pool operator as it will vary according to temperature, chlorine/bromine demand, contamination amount, contamination type, ventilation and the use of ancillary equipment such as pool blankets.

Large swimming pool plants may need to be operated continuously because shut down and start up may be complex and difficult procedures. Conversely, a swimming pool should not necessarily operate continuously for 24 hours. The pool should be operated for its own efficiency and should not waste electricity, gas or ancillary equipment. This is a matter best determined by the pool operator through daily pool operations. It has been suggested that all pools might be operated continuously but with flow reduction during low use and overnight periods.

5.3 Other chemicals used in swimming pools

There is a wide range of chemicals, apart from disinfectants, which may need to be used in the treatment of swimming pools and spa pools. The following are some commonly used chemicals.

5.3.1 Chemicals for raising pH

(i) Soda ash (sodium carbonate Na_2CO_3)

Soda ash is a strong alkali powder or liquid, which is used to quickly raise the pH of a pool. Soda ash should not be added to a pool by slug dosing but should be added slowly and gradually over an extended period when the pool is closed to the public or through the balance tank. It is a dangerous chemical and should be handled by trained personnel with appropriate personal protective equipment. It is mainly used in a 1:1 weight ratio with chlorine gas swimming pool applications as the use of chlorine gas substantially reduces pH. The note below Table 5.3 outlines how this chemical can be added to a pool to increase pH.

(ii) Bicarb (sodium bicarbonate $NaHCO_3$ – pH buffer)

Bicarb is a weak alkali powder, which is used to raise total alkalinity and gently raise pH. It may also be used to contain and neutralise acid spills. Accidental overdosing will not raise the pH to greater than 8.3. Table 5.3 outlines how this chemical can be added to a pool to increase pH.

Table 5.3: Dosage chart to raise pH to 7.5

Pool volume (kL)	Dose of sodium bicarbonate ($NaHCO_3$) to raise pH to 7.5			
	Measured pH			
	5.5	6.0	6.5	7.0
10	0.5 kg	0.36 kg	0.24 kg	0.16 kg
20	1.0 kg	0.72 kg	0.48 kg	0.3 kg
30	1.5 kg	1.08 kg	0.72 kg	0.48 kg
50	2.4 kg	1.8 kg	1.2 kg	0.8 kg
100	7.0 kg	3.6 kg	2.4 kg	1.6 kg

Note: When using sodium carbonate (soda ash) to increase pH to 7.5, halve the quantity i.e. 2 kg sodium bicarbonate (dry alkali or pH buffer) = 1 kg sodium carbonate (soda ash)

Table 5.4: Dosage chart to lower pH to 7.5

Pool volume (kL)	Dose of dry acid (sodium bisulphate NaHSO4) to lower pH to 7.5			
	Measured pH			
	7.8	8.0	8.5	9.0
10	0.05 kg	0.11 kg	0.18 kg	0.26 kg
20	0.1 kg	0.22 kg	0.36 kg	0.52 kg
30	0.15 kg	0.33 kg	0.54 kg	0.78 kg
50	0.25 kg	0.55 kg	0.9 kg	1.3 kg
100	0.5 kg	1.1 kg	1.8 kg	2.6 kg

5.3.2 Chemicals for lowering pH

(i) Dry acid (sodium bisulphate $NaHSO_4$)

Dry acid is a strong acid powder, which may be used to quickly reduce pH and lower alkalinity. Dry acid should not be added to a pool by slug dosing but should be added slowly and gradually over an extended period when the pool is closed to the public or gradually to the balance tank. It is a dangerous chemical and should be handled by trained personnel with appropriate personal protective equipment. Table 5.4 outlines how this chemical can be added to a pool to decrease pH.

(ii) Hydrochloric acid (muriatic acid HCl)

Hydrochloric acid is a strongly acidic liquid, which is highly corrosive and may be used to reduce pH quickly particularly when the reserve alkalinity is greater than 120 mg/L. It is a dangerous chemical and should only be handled by trained personnel with appropriate personal protective equipment.

(iii) Carbon dioxide (CO_2)

Carbon dioxide is a gas which when added to water forms a weak acid (carbonic acid) and may be used to reduce pH when the reserve alkalinity is less than 120 mg/L. It is best used in an automated pH correction system.

5.3.3 Other chemicals

(i) Calcium chloride ($CaCl_2$)

Calcium chloride is added to pools when the water is unbalanced with too little calcium (see Water Balancing in Section 6.4). The addition of calcium chloride raises calcium hardness and prevents damage to pool surfaces. If calcium imbalance is not corrected, the pool water will extract calcium from pool surfaces such as concrete and grout (causing etching).

(ii) Potassium monopersulphate ($KHSO_4$)

Potassium monopersulphate, a white free flowing powder, is also used as a shock treatment to control chloramines in heavily used pools. Potassium monopersulphate works by lowering the chlorine demand by oxidising ammonia, proteins and other pool contaminants. It can improve the disinfection ability of free chlorine and free bromine; and oxidise the hypochlorite and hypobromite ions to the more active hypochlorous and hypobromus acids respectively.

Potassium monopersulphate interferes with the DPD tablet No 3, causing water samples to turn dark red. The monopersulphate is oxidised by this reagent and a false high total chlorine measurement is given although the effect usually ceases after 24 hours.

(iii) Hydrogen peroxide (H_2O_2)

Hydrogen peroxide is a stronger oxidiser than chlorine, but weaker than ozone. On its own it is not a strong disinfectant but it can greatly improve the disinfection ability of free chlorine and free bromine by lowering chlorine/bromine demand by oxidising pool contaminants. It also oxidises hypochlorite and hypobromite ions to the more active hypochlorous and hypobromus acids respectively.

(iv) Ozone (O_3)

Ozone is an excellent oxidiser and an excellent disinfectant. Unfortunately ozone is dangerous if breathed and causes scarring of the lung tissue. For this reason ozone should be quenched, usually by passing the pool water through a granular activated carbon (GAC) bed before the water is returned into the pool. Where ozone is used in an excess of sodium bromide, such as a sodium bromide/ozone system to generate hypobromus acid, no quenching is necessary. (See Table 5.2: The ozone / bromide system).

Ozone has to be generated on site and in the past the capital outlay for ozone generation was cost prohibitive for many pools. More recent technologies decrease the capital costs. Ozone may be generated by corona discharge or UV light technologies. Corona discharge generally produces much larger quantities of ozone.

Ozone may be injected either pre-filter or post-filter depending on the necessity to oxidise organic material in the filter bed. Ozone is always injected and removed before re-chlorination because the GAC bed used to remove ozone will also remove the chlorine.

A recent development is the use of low dose corona discharge ozone where ozone is generated at 1 to 2 grams per hour. The ozone is pumped with air through a venturi into a mixing chamber and reaction vessel in the circulation system after the pool water has been filtered. Provided the ozone is thoroughly mixed and dissolved, it reacts rapidly to destroy chloramines and disinfection by-products to reduce tastes, odours and eye stinging compounds. After an initial milkiness the colour and clarity of the pool water is improved. It is important to ensure degassing before the treated water is returned to the pool. It is not necessary to use GAC to quench excess ozone because the small amount of ozone is either consumed in the reactions or rapidly degrades. Because ozone is a stronger oxidiser than chlorine, it substantially reduces chlorine demand and allows chlorine to be more efficient in residual disinfection allowing for lower chlorine levels (if operating by ORP technology) and less chlorine will be used. The water returning to the pool should be monitored regularly for ozone. A pool cover should not be used. The ozone generator should be located in a well ventilated, dust-free room.

Ozone is not compatible with rubber and some plastics.

(v) Sodium thiosulphate ($Na_2S_2O_3.5H_2O$)

Sodium thiosulphate is a white crystalline substance that is used to reduce excess chlorine in a swimming or spa pool. An adequate small supply of this chemical should be maintained on site in case of an over-chlorination accident. It can also be used to return free chlorine to normal levels after superchlorination. This chemical should not be used in excess, as it will continue to remove free chlorine until all of the thiosulphate has been consumed. Appropriate personal protective equipment must be worn when using this chemical.

(vi) Isocyanuric acid ($C_3N_3O_3H_3$) (Cyanuric Acid)

Isocyanuric acid's weak bonding to hypochlorous acid helps to reduce the degradation of hypochlorous acid to hydrochloric acid in sunlight. See Section 4.4.1 for more information.

(vii) Algaecides

Algae growth is a common problem in outdoor pools, because algae requires sunlight, warmth and nutrients such as nitrogen and phosphorous for growth. Maintaining an adequate concentration of chlorine in pH-controlled pools and regular superchlorination usually prevents algae problems. However, rectification of any pool circulation problems and removal of phosphate may also be necessary to prevent algae growth (see (viii) Flocculants).

Care must be taken to ensure that any chemicals used to treat algae (algaecides) such as copper are approved by the APVMA and do not build up causing possible health risks. The concentration of copper in swimming pools should not exceed 2 mg/L as recommended by the Australian Drinking Water Guidelines (2004).

Swimming pool water containing copper must not be discharged to the general environment, such as the street gutter or watercourses because of the deleterious effects on many life forms and its pollutant nature. All waste pool water should be discharged to the sewer unless properly recycled.

Concentrations of ortho-phosphate exceeding 0.5 mg/L are conducive to algal blooms. Concentrations below 0.2 mg/L should be maintained. Aluminium sulphate, a flocculent [see (viii)], removes phosphates. Lanthanum compounds are also effective as they bond with phosphate to form insoluble phosphate precipitates which can be removed by filtration.

(viii) Flocculants

Flocculants are used to coagulate or aggregate small particles so that they may be more easily removed during sand filtration. Common flocculants include: aluminium sulphate (alum), polyaluminium chloride (PAC), polyaluminium sulpho silicate (PASS) and sodium aluminate. Care must be taken to add flocculants to the circulation system before the filter and in small doses. The pH of the pool should be high enough to prevent the gelatinous flocc which develops on the filter from dissolving and reappearing in the pool. The manufacturer's instructions should be followed carefully.

5.4 Health and safety issues of chemicals

Gas chlorination is an effective swimming pool disinfection system because all of the free chlorine is available for disinfection unlike other disinfection systems. Due to the work health and safety hazards of gas chlorination and the highly onerous installation requirements, it is rarely installed within aquatic centres, although older installations do exist. Many other chemicals have work health and safety hazards. If these hazards are avoided then in most cases public health hazards will also be avoided.

The NSW WorkCover Authority regulates the storage and handling of dangerous goods and should be consulted to obtain the necessary occupational, health and safety requirements for the storage and handling of swimming pool and spa pool chemicals. The NSW WorkCover Authority website URL is: www.workcover.nsw.gov.au

The requirements of the WorkCover Authority are expressed in their document *Storage and Handling of Dangerous Goods – Code of Practice* (2005) which can be downloaded from the WorkCover Authority website. (Catalogue Number WC01354).

WARNING: Never add acid directly to a chlorine-containing substance as chlorine gas will be generated and released.

Never add water to a powder, granular or solid compound; always slowly add the compound to water while stirring.

One of the greatest hazards of handling chemicals is slug dosing directly into swimming pools. This should never be done directly into swimming pools or spa pools when the pool is open to the public. If performed, appropriate personal protective equipment must be worn.

5.5 Disinfection by-products

Disinfection by-products (DPBs) are unwanted chemicals that may form during the disinfection process. Some of these chemicals such as the trihalomethanes, chlorate, chlorite and bromate can cause latent health problems.

In properly managed pools evidence suggests that the low concentration of these chemicals should not pose a risk to public health (WHO 2006). The most common chemical disinfectants used in pool water treatment are listed in Table 5.5 together with the DPBs that could form.

Very few DBPs are caused through the addition of water from the water mains. DBPs are more likely to arise from pollutants introduced by bathers and therefore bathers should be encouraged to toilet and shower before entering a pool.

Table 5.5: Chemical disinfectants and their disinfection by-products

Disinfectant	By-product
Chlorine/hypochlorite	Trihalomethanes Haloacetic acids Haloacetonitriles Haloketones Chloralhydrate (trichloroacetaldelhyde) Chloropicrin (trichloronitrimethane) Cyanogens chloride Chlorate Chloramines
Ozone/bromine	Bromate Aldehydes Ketones Ketoacids Carboxylic acids Bromoform Brominated acetic acids
Chlorine dioxide	Chlorite Chlorate
Bromine/hypochlorite Bromo-chloro-dimethylhydantoin	Trihalomethanes, mainly bromoform Bromal hydrate Bromate Bromamines Dimethylhydantoin
Chlorine/bromine with copper Silver	Silver (0.1 mg/L) Copper (2 mg/L)

Based on WHO 2006 and the Australian Drinking Water Guidelines 2004

5.6 Frequency of pool testing

It is a **mandatory requirement** (prescribed operating requirement of Schedule 1, *Public Health Regulation 2012*) for all non-automatic continuously dosed public swimming pools that the disinfectant and pH levels be tested prior to the opening of the pool. The disinfectant and pH levels shall then be tested as frequently as determined by the pool operator depending on the circumstances of pool operation.

It is a **mandatory requirement** (prescribed operating requirement of Schedule 1, *Public Health Regulation 2012*) that the disinfectant and pH levels of automatically dosed public pools be recorded prior to opening and once during the opening period. Additionally, the public pool shall be manually tested once a day.

Other mandatory requirements (prescribed operating requirement) are marked by an asterisk (*****) in Table 5.6.

The following recommendations on the frequency of manual pool chemical testing are risk based. This risk is determined according to whether a pool is automatically dosed and the likelihood of a large rapid change in bathing loads. A motel or hotel pool tends to be low risk while learn-to-swim centres for infants are high risk. Spa pools and hydrotherapy pools are all generally high risk.

Evidence has shown that pools which are automatically dosed and frequently tested are more likely to be adjusted according to the bathing load to comply with the criteria. Unfortunately, most manually dosed pools are not frequently tested and studies have shown that these pools are less likely to comply with the criteria (Ford 2004). Testing of pool water to determine its disinfection capacity and to protect public health should be carried out in accordance with the requirements of Table 5.6.

Table 5.6: Swimming pool and spa pool testing frequency

Test	Recommended Minimum Manual Testing Frequency (Mandatory Testing Frequency = *)
Non-automatic continuous dosing /metering high risk[(1)] pools:	
■ Free chlorine / bromine ■ Total / combined chlorine	■ Prior to opening* and thence every **two** hours (or every **one** hour when bather loads exceed design capacity)
■ pH	■ Prior to opening thence as deemed necessary*
Non-automatic continuous dosing / metering low risk pools:	
■ Free chlorine / bromine ■ Total / combined chlorine	■ Prior to opening* and thence every **four** hours when there is a bather load.
■ pH	■ Prior to opening thence as deemed necessary*
Automatic control dosing: ■ Free chlorine/bromine (ORP) ■ Total / combined chlorine ■ pH	■ Once during the day to confirm automatic readings* (provided that there is in-line automated testing and recording which is checked and logged hourly)
Other Tests:	
■ Total alkalinity	■ Daily * ■ Weekly if using liquid chlorine disinfection or carbon dioxide (CO_2) pH control*
■ Turbidity and/or clarity ■ Ozone ■ Cyanuric Acid ■ Water balance	■ Weekly ■ Weekly* ■ Weekly* ■ Weekly
■ Total Dissolved Solids ■ Dimethylhydantoin (BCDMH systems)	■ Monthly ■ Monthly

High risk pools include spa pools, hydrotherapy pools, baby and infant learn to swim pools, infant wading pools, water features in pools, pools used by incontinent people, or a pool with three or more of the following risk factors:

- pH greater than 7.6 in a chlorinated pool
- Consistently poor disinfection (previous chemical or bacteriological criteria failures).
- High turbidity
- Poor pool circulation and/or filtration
- High bather loads
- Presence of algae
- Regular use by birds e.g., ducks
- Easy access of foreign material e.g., litter
- Biofilms detected
- Poor quality make-up water (high in chloramines)

5.7 Sampling location

Water samples for chemical testing should be tested immediately after collection. Water should be sampled from a depth of at least 450 mm using an inverted plastic (not glass) beaker in a location away from the inlets (returns). Except for ozone testing, a water sampling point closer to the outlets, gutters or wet deck return, should be selected because it represents the quality of the water leaving the pool. The plastic beaker should be rinsed in the pool water, emptied and then the sample taken by plunging the inverted plastic beaker into the pool, inverting and lifting in the one scooping motion in the direction opposite to the water current.

Water samples for testing ozone should be collected in the same manner as above in a location representing a point closest to an inlet (return).

Sampling to confirm automatic control dosing should be taken from a sample tap strategically located on the return line as close as possible to the control probes and in accordance with any manufacturer's instructions.

As the difference between manual pool readings and automatic control measurements will vary, it is the consistency of variation that is paramount. Diverging or converging readings should be investigated.

For microbiological sampling and testing refer to Chapter 3.

5.8 Testing equipment and testing

Suitable testing equipment needs to be used to ensure accurate results. All glassware and plastic ware should be thoroughly washed and rinsed after each testing session. The test methodology specified by the manufacturer of the test kit should be strictly followed. Plastic or Perspex® kits known as '4 in 1' or '5 in 1' kits for backyard pools or test strips are not suitable for testing public swimming pools and spa pools. Photometric test kits are the most reliable test kits, and should be used in preference to colorimetric kits. Males with red/green colour blindness cannot use colorimetric kits.

Testing should be performed in the shade preferably in a cool, well lit room. Tests of the most volatile chemicals, such as ozone, free chlorine and free bromine should be conducted immediately. If possible, temperature should be measured directly from the pool.

Table 5.7: Chemical testing equipment

Water quality parameter	Best Practice Test kit / Methodology
Chlorine/bromine	Photometric method based on DPD reagents capable of measuring to 0.1 mg/L units within the recommended disinfectant range
Ozone	Photometric method based on DPD reagents
Hydrogen peroxide	Photometric method based on potassium iodide under acidic conditions and capable of measuring in 10 mg/L increments within the range of 0-100 mg/L; Any electronic meter
pH	pH meter Photometric method
Total alkalinity	Photometric method
Cyanuric acid	Photometric based method within 0-200 mg/L range
Clarity	Water clarity should be maintained 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
Copper	Photometric method
Chlorite	Photometric method or laboratory analysis
Bromate	Photometric method or laboratory analysis
Bromide	Laboratory (test kits test do not necessarily differentiate between bromide and chloride)
Dimethylhydantoin (DMH)	Photometric method or laboratory analysis
Sulphate	Photometric method or laboratory analysis
Turbidity	Any test apparatus capable of measuring to 0.5 nephelometric turbidity units Laboratory analysis; Turbidity meter
Silver	Photometric method or laboratory analysis
Total trihalomethanes	Laboratory analysis
Total dissolved solids (TDS)	TDS meter, laboratory analysis or sensor (measured as conductivity)
Phosphate	Photometric method or laboratory analysis
Oxidation-reduction potential (ORP)	An electronic ORP meter

1. All equipment needs to be checked and calibrated in accordance with the manufacturer's specifications and maintenance manuals.
2. Bleaching of DPD reagents occurs when free chlorine concentration is high and will give a false low reading. The manufacturer's manual should be followed and a dilution prior to testing should be performed if free chlorine is suspected of being higher than 5 mg/L.

Table 5.8: Other chemical and physical criteria for swimming pools and spa pools

Parameter	Maximum criteria
Temperature (mandatory maximum value)	38°C. A sign should be erected near high temperature pools warning of the dangers of heat stress from bathing for too long. High temperature pools should not be used for laps and aerobic exercise due to potential health risk from heat stress
Total dissolved solids (TDS)	As a general rule, TDS should not be permitted to rise to more than 1500 mg/L above the source water and should not be permitted to exceed 3000 mg/L
Turbidity	1.0 nephelometric turbidity units
Dimethylhydantoin	200 mg/L
Copper	2 mg/L
Silver	0.1 mg/L
Total trihalomethanes	0.25 mg/L
Chlorite (disinfection by-product of chlorine dioxide)	0.3 mg/L
Chlorate (disinfection by-product of chlorine dioxide)	0.7 mg/L
Bromate (disinfection by-product of bromine/ozone pools	0.02 mg/L

Fresh tablet reagents in unbroken foil should be purchased frequently and stored under optimal conditions specified by the manufacturer. Similarly, fresh liquid reagents should be stored as a minimum in dark, cool conditions until just before use at each test. Out-of-date reagents should be discarded. Table 5.7 lists the water quality parameter and the best type of kit or methodology appropriate for that test.

5.9 Other chemical and physical parameters

Table 5.8 is a list of common chemical parameters or physical attributes and a recommended maximum criterion for each. Temperature has a mandatory maximum value of 38°C specified in Schedule 1, *Public Health Regulation 2012*. The recommended values are not stringent and are provided as a guide only. Some of the values have been taken from the Australian Drinking Water Guidelines (2004).

5.10 Record keeping

It is **mandatory** that records of all mandatory tests be kept for six months.

A log sheet or register should be used to record the results of every test performed at a swimming pool, spa pool or pool complex. The keeping of records is a professional activity and can be used to demonstrate competency in pool operations. Log books containing all of the log sheets should be maintained in a register for assessment of any technical issues and problems that may arise. Log sheets tend to be individual for each premises and location.

Where automated in-line tests are recorded electronically, these should be downloaded monthly and kept with any other records. It is also possible to represent the data graphically which may add further meaning to the results. For example, free chlorine may be graphed against bather loads.

The items in Table 5.9 may be included in a log sheet and those items marked with a "#" are considered essential. One person should be responsible for pool testing and recording of results each working shift and the log sheet should bear their name.

Table 5.9: Suggested items to be included in a log sheet (# = essential)

- # date and time of test
- # disinfectant concentrations
- pH
- # total alkalinity
- # temperature
- bathing loads
- operational comments
- total dissolved solids (TDS)
- # cyanuric acid concentration
- water meter reading
- electricity meter readings
- admission data
- dose settings
- mechanical maintenance items
- # oxidation-reduction potential (ORP) (if applicable)
- chemical usage and stocks on hand
- backwashing
- water balance

An example of a log sheet is contained in Appendix B which is also available in MS Word format from the NSW Department of Health website: http://www.health.nsw.gov.au/.

CHAPTER 6

Managing water quality

6.1 Overview

The effective management of swimming pool and spa pool water quality is dependent upon:

- An efficient pool water circulation and filtration system to adequately remove pollutants and effectively distribute residually disinfected water throughout the pool
- A water disinfection system which maintains a set disinfectant concentration (or ORP) upon demand (i.e. will adjust to varying bather loads)
- Balanced water to ensure bather comfort and protection of pool materials and equipment
- A trained and experienced pool operator capable of monitoring and rectifying pool water quality problems.

This chapter considers maintenance of pool water quality and disinfectant concentrations. Topics discussed include automatic dosing equipment, water balancing, backwashing and reuse of backwashing wastewater, minimising pool pollution and chloramine control.

6.2 Chlorine demand

Once the required free chlorine (or bromine) residual has been achieved with the minimum of combined chlorine, there are many pollutants and weather conditions that will consume the disinfectant in chemical reactions and quickly reduce the free residual chlorine concentration. Such pollutants and conditions in pools include:

- Sunlight/shade
- Indoor/outdoor
- Aeration/ventilation
- Wind and wind-blown debris, particularly debris high in organic matter
- Rain
- Bather pollution: perspiration, urine, cosmetics, faecal material, sputum, vomitus, dead skin cells, hair, lint and micro-organisms.

The amount of chlorine that needs to be replaced to maintain the desired free residual is known as chlorine demand. Most of the chlorine is consumed by reaction with organic material and sunlight rather than in disinfection of micro-organisms. Chlorine demand is reduced by filtration and backwashing, and by occasionally supplementing chlorine with alternative oxidisers such as hydrogen peroxide, UV light, ozone or potassium monopersulphate.

In order to maintain the desired free chlorine residual for rapid disinfection, the chlorine dose has to be matched to chlorine demand. This matching cannot be done easily with just a continuous dosing system unless the pool operator is constantly sampling the pool and adjusting the dose in anticipation of chlorine demand. Matching of chlorine dose to chlorine demand can more easily and effectively be achieved with automatic chemical dosing equipment. For this reason, automatic dosing equipment is considered to be best practice.

6.3 Chemical dosing control equipment

Automatic chemical dosing for disinfectant (chlorine or bromine) and pH control is the most effective mechanism to match residual disinfectant control to demand. There are two main technologies available to achieve automatic dosing:

- Oxidation-reduction potential (ORP) using millivolts (mV)
- Amperometric, using mg/L of disinfectant.

Clause 3(1), Schedule 1, *Public Health Regulation 2012,* requires that a pool must be fitted with an automated or a continuous metered disinfectant dosing system.

6.3.1 Continuous metered disinfectant dosing system

A "continuous metered disinfectant dosing system" is a device or apparatus which delivers the disinfectant in a positively controlled continuous and steady rate.

The disinfectant should be delivered at some point into the pool circulation system and not directly into the pool. It is preferable that the disinfectant be added just after the filtration system to lessen the formation of disinfection by-products.

A pump which delivers liquid chlorine at a particular rate i.e. millilitres per hour, is a good example of a continuous metered disinfectant dosing system. Other examples include dry chemical feeders, and electrolytic disinfectant generation.

Obviously hand dosing or broadcasting is not a continuous metered disinfectant dosing system. Similarly a floating device with a block of dichloroisiocyanurate is not a continuous metered disinfectant dosing system. An erosion feeder is not a continuous metered disinfectant dosing system unless it can deliver the disinfectant at a constant rate instead of at a diminishing rate.

One of the cheapest forms of a continuous metered disinfectant dosing system is a peristaltic pump drawing from a shaded drum of liquid chlorine (sodium hypochlorite) and slowly injecting the liquid chlorine into the pool circulation system after the filter. The peristaltic pump can be set up to deliver a dose of chlorine at particular time intervals. A continuous metered disinfectant dosing system can also be controlled by a timing switch to activate it at some time prior to opening and de-activate it at some time after closing. The dosing rate or frequency on some pumps can be varied allowing the pool operator greater scope in delivering disinfectant to the pool at varying continuous rates.

6.3.2 Oxidation-reduction potential

Oxidation-reduction potential (ORP, redox) measures the rate of oxidative disinfection caused by the addition of the effects of all oxidants in the pool water. ORP is determined by using a high quality ORP probe and meter. The unit of measurement of ORP is millivolts (mV).

Oxidisers (mainly disinfectants) consume electrons while reductants (mainly contaminants) donate electrons. As chlorine is continuously added to the swimming pool the disinfection action is mainly due to chlorine compounds, particularly hypochlorous acid (HOCl). The ORP is the potential of a disinfectant to do its work of inactivating micro-organisms and oxidising organic materials. The higher the millivolt reading, the more powerfully the swimming pool water is able to oxidise and disinfect.

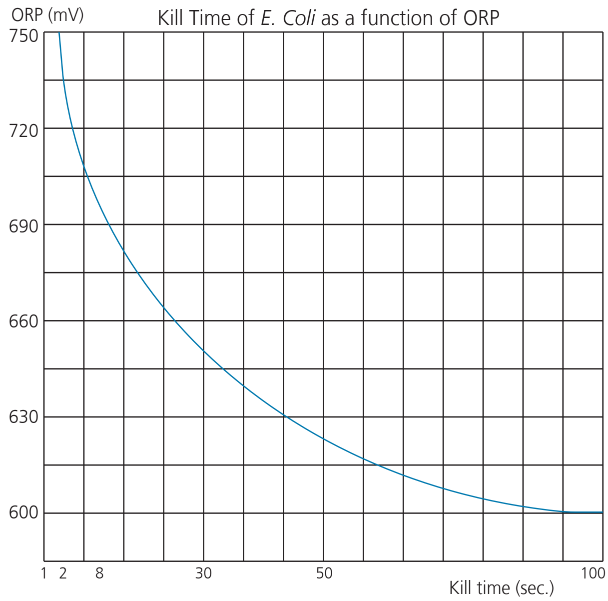
Oxidisers cause the millivolt value to increase and therefore increase disinfection. Typical oxidisers are hypochlorous acid (a component of free chlorine), ozone, hydrogen peroxide, and potassium monopersulphate.

Reductants cause the millivolt value to decrease and therefore decrease disinfection. Typical reductants are the hypochlorite ion (a component of free chlorine), chloramines, cyanuric acid, organic matter (dust and dirt), urine, perspiration, sputum, micro-organisms, cosmetics, and faecal material.

A drop in the ORP indicates an increase in chlorine demand caused by reducing agents or contaminants entering the water. A decrease in ORP indicates that chemical reactions are about to occur. Compared to amperometric control, ORP is considered to be a more accurate measure of disinfection rate. Also, ORP controllers can automatically add disinfectant according to demand. They therefore anticipate the disinfecting and oxidising chemical reactions that are about to occur.

ORP is an indicator of micro-organism inactivation. Studies on specific micro-organisms have found a direct correlation between increasing ORP and micro-organism inactivation as shown in Graph 6.1. Drinking water is adequately disinfected at an ORP of 650 mV. In swimming pools, an ORP of 700 to 720 mV allows for both a quick disinfection and for breakpoint chlorination (destruction of chloramines) where conditions permit.

Graph 6.1: Kill Time for a log 3 Reduction of *E. coli* as a function of ORP



Source: Eutech Instruments Pty Ltd

The ORP value required in swimming pools is higher than that required for water supplies because contamination is constantly being added to swimming pools.

Section 4.4.1 (ii) *The effect of pH on chlorine disinfection power*, explained that pH affects the concentration of hypochlorous acid (HOCl) while the concentration of free chlorine remains the same. An increasing pH decreases the concentration of HOCl and hence its disinfection power. Similarly a decreasing pH increases ORP because the oxidative power of free chlorine increases.

ORP measurement correlates weakly with free chlorine measurement because they measure two different entities. ORP measures oxidative disinfection power not the concentration of free residual chlorine. Free chlorine measures the concentrations of hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-) not the oxidation disinfection power. Free chlorine is a variable component of ORP. Oxidative disinfection does not correlate well to free chlorine for two reasons:

- When free chlorine exists as the hypochlorite ion (OCl^-) the ORP will be low. This will occur when the pH is high. Therefore free chlorine could be high and the ORP low at a pH greater than 7.6.
- Reductants lower ORP. Therefore free chlorine could be high, but the ORP will be low if combined chlorine is high, cyanurate is present, contamination is high, etc.

A pool with satisfactory ORP could have low free chlorine if the reductants are low. That is, there is low combined chlorine (i.e. breakpoint chlorination), low pH, no cyanuric acid, and low organic contaminants. Such a pool will have satisfactory disinfection power.

It is often difficult to obtain a satisfactory ORP reading in an outdoor pool stabilised with cyanuric acid. It may be necessary to limit the cyanuric concentration to 25 mg/L or even 20 mg/L to obtain a satisfactory ORP reading.

It is often difficult to obtain a satisfactory ORP reading in an indoor pool with excessive combined chlorine. It may be necessary to control combined chlorine by the installation and use of medium pressure UV light lamps or low dose ozone to obtain a satisfactory ORP reading.

ORP will also vary according to the water source used to fill the swimming pool. ORP will vary according to the materials used to construct the swimming pool.

However, the constant is that ORP is an accurate measure of killing power as it takes all of the variables into account due to the combined effect of their respective ORP values.

Careful calibration of the probe and controller is required. There are two methods or calibration:

- By the use of buffer solutions, and
- By using electronic calibrators

It is essential that the ORP system is calibrated every six months by an independent person who might reasonably be expected to be competent to do so and a certificate of calibration should be obtained.

Where shock oxidation or superchlorination is practiced, the shock dose will temporarily raise the ORP. Shock oxidisers tend to raise the ORP short term whereas superchlorination raises ORP for a longer period.

To detect and prevent failures due to instrument errors, ORP should be checked against manual free and total chlorine measurement daily and the probes and other equipment must be regularly maintained in accordance with the manufacturer's specification.

6.3.3 Direct chlorine residual measurement (amperometric)

There are two types of amperometric free chlorine sensing probes commonly available:

- Membrane amperometric probes
- Potentiostatic three electrode amperometric probes

Membrane amperometric probes measure free chlorine using platinum or gold covered membrane and a silver/silver chloride covered membrane.

The other type of amperometric probe is known as potentiostatic three electrode amperometric (or tri-amperometric) and uses an integral electrolyte salt supply for probe buffering. Quartz grit is used for hydro-mechanical self cleaning of the sensor tip in a specially designed flowcell ensuring probe reliability, stability and accuracy in the constantly varying water conditions of heavily loaded swimming pools. This type of probe has an advantage over the membrane chlorine probe as it is lower in maintenance, needs no membrane cap replacement and is cheaper to replace.

The amperometric method of control relies on measuring free chlorine (hypochlorous acid) using probes which are calibrated at specific set points. Unlike ORP, which gives a good measure of disinfection, a pool operator using the amperometric method may inaccurately believe that disinfection is adequate based on free chlorine alone. To effectively use amperometric control, a pool operator needs to understand that disinfection efficiency is affected by interferences from extremely high TDS, turbidity, chloramines, high pH and cyanuric acid, and to continually monitor these parameters to prevent poor disinfection.

The amperometric method places greater reliance on a skilled pool operator to ensure the maintenance of water quality for good disinfection rates.

6.3.4 Automatic controllers

Recently, some overseas manufacturers have developed advanced controllers which are reported to make the most of the benefits of each sensor technology and are capable of combining the inputs of both free chlorine probes, total chlorine probes and/or redox (ORP) probes using patented control algorithms. This approach ensures both consistent disinfection under varying water conditions and reliable free chlorine residual levels. This technology is soon to be introduced into Australia.

6.3.5 pH probes

pH probes and automatic pH control are best practice for maintaining disinfection concentration and disinfection power. The pH probe needs to be calibrated regularly and should be serviced and cleaned regularly in accordance with the manufacturer's specification.

6.4 Water balancing

6.4.1 Overview

The term 'chemical water balance' means that pH, total alkalinity and calcium hardness are within an optimum range to prevent calcium scaling, calcium corrosion and bather discomfort.

Balanced pool water prolongs the life of a pool and its fittings, assists with preventing stains and improves bather comfort. Where dissolved salts in the pool water are too high, salt precipitates out of solution and deposits known as scaling may occur. Scale is more likely to form within heating units because as the temperature of water increases the solubility of calcium decreases. However, scale may also form within pipes and can cause mud balls within filters.

Water balance is most significantly affected by:

- pH
- Total alkalinity
- Calcium hardness
- Temperature

Total dissolved solids (TDS) have a minor effect on swimming pool water balance unless at an extremely high level not normally encountered in swimming pools. TDS has a major effect in high evaporative water use in devices such as boilers and cooling towers. This is further discussed in section 7.6.2.

6.4.2 pH

pH is a measure of the hydrogen ion concentration in water or more simply a measure of how acid or alkaline a pool is. The pH scale ranges from 0 to 14, with 7.0 being neutral. A pH below 7.0 indicates acidic conditions and a pH above 7.0 indicates alkaline conditions. To maintain disinfection levels and bather comfort, pH should be maintained between 7.2-7.6 (maximum 7.8). At a pH below 7.2 there is discomfort to bathers and corrosion to pool equipment. See section 4.4.1 for a discussion on the effect of pH on chlorine disinfection.

6.4.3 Total alkalinity

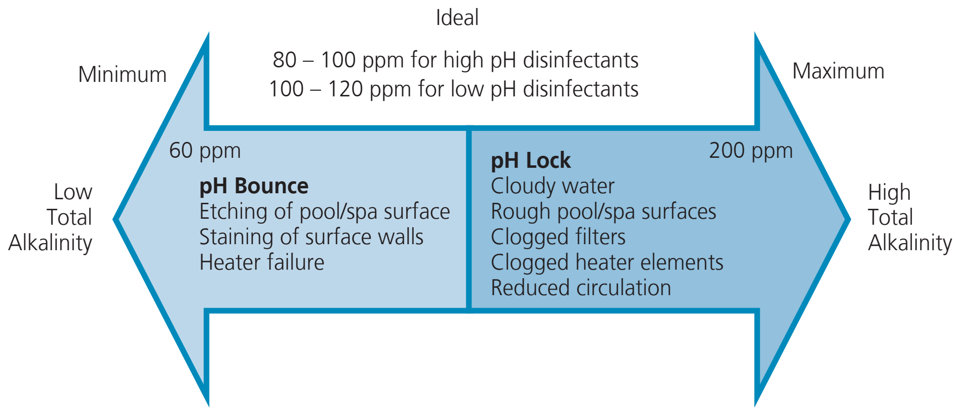
Total alkalinity is a measure of the alkaline salts (bi-carbonates, carbonates and hydroxides) present in water. Total alkalinity prevents large fluctuations in pH, known as pH bounce. To increase total alkalinity, a buffer such as sodium bicarbonate is added to the water; to lower total alkalinity, acid is added. pH will need to be re-adjusted as a change in total alkalinity alters pH. Table 6.1 is an overview of total alkalinity levels.

6.4.4 Calcium hardness

Calcium hardness is a measure of the amount of dissolved calcium salts present in the water. Pool water that is very high in calcium hardness can cause scaling of heaters and pool finishes. Pools that have low calcium hardness can cause corrosion of pool equipment and etching of cement and tile grout.

Some raw water sources from rural areas are naturally hard (hardness over 250 mg/L $CaCO_3$) making these water sources more suited to treatment using sodium hypochlorite rather than calcium hypochlorite. Similarly, soft waters (hardness under 50 mg/L $CaCO_3$) should be treated with an alkaline disinfectant such as calcium

Table 6.1: Total alkalinity-related pool problems



hypochlorite or sodium hypochlorite plus calcium chloride, and a gentle acid such as carbonic acid from carbon dioxide should be used to decrease pH with a gentle buffering effect. A pool consultant should be engaged to determine the most suitable pool treatment system.

6.4.5 Temperature

Temperature has an important effect on water balance, mainly because calcium salts become less soluble at higher temperatures. Hence high temperature pools are often subject to scaling as the calcium salts deposit on equipment and pipes. At a lower temperature the water can absorb more calcium which could cause etching of pool surfaces.

6.4.6 Langelier saturation index

In order to measure or to give an indication of the solubility of calcium carbonate ($CaCO_3$) in the swimming pool water, the Langelier saturation index (LSI) is used. There are four parameters that need measuring and input into a formula to calculate the index:

- pH
- Temperature – temperature factor (TF)
- Total alkalinity – alkalinity factor (AF)
- Calcium hardness – calcium factor (CF).

The LSI formula is:
pH + TF + AF + CF – 12.1 = LSI where 12.1 is an adjustment constant. The ideal result for the LSI is –0.2 with a range of –0.5 to + 0.5.

The temperature factor (TF), the alkalinity factor (AF) and the calcium factor (CF) are obtained from using the Tables below and extrapolating factors as required.

Table 6.2: Temperature factor (TF)

Temperature °C	Factor
0	0.0
3	0.1
8	0.2
12	0.3
16	0.4
19	0.5
24	0.6
29	0.7
34	0.8
41	0.9

Table 6.3: Alkalinity factor (AF)

Total alkalinity (mg/L)	Factor
5	0.7
25	1.4
50	1.7
75	1.9
100	2.0
150	2.2
200	2.3
300	2.5
400	2.6
800	2.9

Table 6.4: Calcium factor (CF)

Calcium hardness (mg/L)	Factor
5	0.3
25	1.0
50	1.3
75	1.5
100	1.6
150	1.8
200	1.9
300	2.1
400	2.2
800	2.5

Example LSI calculation

A hydrotherapy pool is tested and the following results determined:
pH 8.2; total alkalinity 200 mg/L; calcium hardness 800 mg/L and temperature at 33°C.

LSI = 8.2 + 0.8 + 2.3 + 2.5 – 12.1 = +1.7

The index is too positive and needs to be lowered to less than +0.5 to prevent scale forming. The temperature is fixed so adjustments need to be made to the other parameters. pH needs to be adjusted to 7.5 (which also improves the disinfection power of chlorine), total alkalinity to 150 mg/L and calcium hardness to150 mg/L.

LSI = 7.5 + 0.8 + 2.2 + 1.8 – 12.1 = +0.2

6.4.7 Corrosive water – the Ryznar index

The Ryznar index (RI) should be used to predict more accurately than the LSI the scaling or corrosive tendencies of swimming pool water.[37] Similar to the LSI, the RI uses pH, pool temperature, calcium, total alkalinity and TDS to calculate the pH of saturation (pHs) and then the RI. There are various RI calculators that can be found on the web, for example
http://www.lenntech.com/ro/index/ryznar.htm

Ryznar index example

Consider a swimming pool with the following water chemistry parameters:
pH 7.5;Temperature 27°C; Calcium 250 mg/L; Total alkalinity 100 mg/L; TDS 2000 mg/L

The pH of saturation (pHs) for this water is calculated at 7.4 and an RI of 7.3 (using the above URL reference). Based on these parameters, the LSI equates to 0.1. However the Ryznar index of 7.3 indicates that a corrosive condition exists. Ideally water should be maintained within the RI range of 6.3 – 6.7 with 6.5 being the ideal target.

The above example shows that water with an acceptable LSI can be corrosive. For additional information regarding corrosion or water balance a pool specialist should be contacted.

6.5 Backwashing of sand filters

Regular backwashing of sand filters in accordance with the manufacturer's specification is essential for proper cleaning, maintenance and operation of pool filters. Backwashing, when indicated by a back pressure gauge, is done by reversing the flow of pool water through the filters allowing the trapped material to flow to waste. Backwashing should continue until the backwash water runs clear. Some backwashing systems have a rinse cycle. A well cleaned filter greatly assists filtration.

Swimming pool backwash wastewater consists of all of the pollutants that are filtered from a pool. The majority of pollutants are introduced into the pool from bathers. Backwash water may be heavily polluted with a wide range of pathogenic micro-organisms, and chemicals from oil, lotions, urine, detergents, saliva, faeces and disinfection by-products. While some sections of the swimming pool industry advocate the occasional addition of liquid soap during backwashing to remove grease and oils from the sand, the filter manufacturer should be contacted for an opinion.

6.5.1 Reuse of backwash water (externally)

Usually the wastewater generated from backwashing is discharged to the sewerage system in accordance with a trade waste agreement with the local sewerage authority. Trade waste agreements are becoming more expensive. As water is scarce in many areas of Australia, treated backwash water is increasingly being reused for cleaning and irrigation purposes and, highly treated, for recycling into the pool and for toilet flushing.

Under no circumstances should backwash wastewater be directly discharged to the environment or to the stormwater system. The wastewater is extremely harmful to the environment and promotes weed growth in natural bushland areas.

The backwash wastewater may be suitable for reuse on parks and gardens or for dust suppression on road works if properly assessed and pre-treated. Untreated and un-disinfected backwash wastewater must never come into direct contact with people.

The reuse of backwash wastewater must be fully assessed and a water reuse plan developed. A health risk assessment should be performed using *Environmental Health Risk Assessment – Guidelines for assessing human health risks from environmental hazards*.[38]

Issues to consider in the health risk assessment include:

- Reduction of salinity / total dissolved solids
- Potential reuse options
- Storage
- Savings on discharge to trade waste
- Costs of reuse
- Environmental grants
- Treatment / pre-treatment / disinfection

The advice of a consultant in developing reuse options is recommended.

6.5.2 Recycling of swimming pool backwash wastewater

Backwash water

Backwash water may be heavily contaminated with pathogenic micro-organisms and harmful chemicals. Backwash water should never be reused or recycled without adequate treatment.

To conserve water, recycling of treated backwash water to top-up swimming pools and spa pools is supported provided the backwash is treated to an acceptable standard and controls are in place to protect public health.

Recycling swimming pool backwash water involves treatment to a suitable standard to allow recycling into the pool. As pool water will be accidentally swallowed, the quality of recycled backwash water should meet the *Australian Drinking Water Guidelines (2004)*[39] and controls need to be in place to protect against system failures. Any deviations from these guidelines should be supported by a health risk assessment. The National Water Quality Management Strategy, *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1)* should be used as a guide.[40] *Environmental Health Risk Assessment – Guidelines for assessing human health risks from environmental hazards (*2002*)* also includes useful information.[38]

Appendix C provides an example of some of the components to consider for recycling of swimming pool backwash water based on *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1).* [40]

Reverse osmosis is presently the best available technology for the treatment of backwash water for recycling. Pre-treatment using ultra-fine filtration and granular activated carbon may be necessary to prolong the life of the reverse osmosis membrane.

Reverse osmosis has been shown to remove the majority of dissolved contaminants (more than 99.5% dissolved salt and up to 97% of most dissolved organics), and 99.99% of micro-organisms. However because of the high set up, operational and maintenance costs, the cost of recycling backwash may outweigh any benefits.[40] Reverse osmosis should be installed with supporting treatments to greatly enhance its efficiency. The advice of a consultant in designing a recycling plant is essential.

6.6 Minimising pool pollution

6.6.1 Restricting bather load and encouraging bather hygiene

Restricting bather loads and encouraging bathers to toilet and shower before using a public pool is important for maintaining water quality. Filtration systems are designed for a maximum bather load and this limit should not be exceeded. The bather load should be expressed and documented by the pool designer.

Additional strategies to maintain water quality through patron behaviour are recommended in Chapter 8, section 8.5, *Education*.

6.6.2 Total dissolved solids

Total dissolved solids (TDS) increases as minerals and chemicals dissolve in water. TDS is an indication of the total amount of the dissolved solids in the water. As TDS increases so does the conductivity of the water. Conductivity can be measured in the field while TDS cannot. An estimation of TDS is therefore made from conductivity.

The main effect of TDS is to indicate the possible corrosiveness and solubility of minerals in water. As TDS rises the concentration of corrosion inducing ions increases and the oxidisers efficiency generally improves, unless the main component of TDS is reductants. However, if pools are properly balanced according to the Ryznar Index (see section 7.4.7) the effect of TDS on corrosion or scaling is negligible.

A high TDS may indicate a high salinity and salty taste that is caused by a high concentration of sodium ions. A high TDS may also indicate a build up of disinfection by-products or organic chemicals that cannot be readily removed from solution. Specific chemical testing is required to identify and determine a course of action. High TDS is also a confounder which may affect both ORP and amperometric sensing equipment.

TDS (and conductivity) is more important in industrial processes where high evaporation rates lead to high TDS. This situation occurs in cooling towers and boiler applications but in swimming pools it has a minor effect overall.

To reduce TDS levels, water dumping which occurs during backwashing, followed by dilution with fresh water with a low TDS is needed. Alternatively, reverse osmosis can be used but this is an expensive process to control a minor effect.

6.6.3 Water sources

(i) Mains water

The quality of the water source used to fill and top-up the swimming pool needs to be regularly checked for the basic parameters of free chlorine, total chlorine, pH, alkalinity, ORP, turbidity, TDS and colour. The incoming water may greatly affect the swimming pool water quality. For example, disinfection of the mains water may be by the use of chlorine and ammonia – a process known as chloramination which may elevate the pool combined chlorine concentration and prevent breakpoint chlorination.

Although the mains water may be disinfected it may not be filtered. This could lead to temporary clarity and sediment problems. It is appropriate that mains water is introduced into the pool either through the balance tank or at night to allow sufficient time for treatment before bathers enter the pool.

(ii) Borewater

Some bore waters are hard and high in calcium and magnesium carbonates. Such water may cause difficulties in balancing pool water, heating and scaling. The use of calcium hypochlorite as a disinfectant may worsen the problem. The advice of water treatment experts should be sought.

(iii) Rainwater (roof water) harvesting

The use of filtered clean rainwater collected from the roof (not general stormwater runoff) to fill spa pools and swimming pools is supported provided controls are in place to protect public health. Rainwater collected in tanks can be safely used for pools provided it is introduced into the pool through either the balance tank or into the pool at night to allow sufficient time for treatment before bathers enter the pool.

Safe rainwater use for swimming pools is achievable in most situations, unless rainwater is collected from roofs either constructed of hazardous materials (such as lead or preservative-treated timber) or located in heavily polluted areas where particulate pollution from vehicles, aircraft and industrial activities may contaminate rainwater.

First flush systems effectively minimise particulate and microbial pollution. First flush systems reduce contamination because the first few litres of rainwater, which contain the highest concentration of pollutants, are discarded to stormwater. First flush systems have been installed in various industrial and commercial applications and have proved to be a reliable way of reducing rainwater contamination. Microbial contamination of rainwater can also be easily controlled by chlorination in the collection tank. The area of the roof being used needs to be considered when determining the quantity of first flush water to discard.

Rainwater can have the added benefits of being low in TDS and being soft water, i.e. low in carbonates.
In heavily polluted areas, the cost of pre-treatment to maintain safe water may outweigh any benefits, especially where a reliable water source exists.

Further information is contained in *Rainwater Tanks* [41] and *Guidance on use of rainwater tanks*.[42]

The use of filtered clean rainwater to top-up swimming pools is supported provided controls are in place to protect public health. A suggested risk assessment and management framework is outlined in Annexure D.

6.7 Prevention and control of chloramines in indoor aquatic centres

Chloramines can cause eye and respiratory irritations, interfere with disinfection, place extra demands on chlorine and ruin the fun of swimming. They must be maintained below 1mg/L. The following measures may assist to prevent and control chloramines particularly in indoor aquatic centres. Refer to section 4.4.1 for a discussion on chloramines.

6.7.1 Education

Bather hygiene is essential to prevent excess chloramine formation. Educational strategies and pool policies should encourage or require patrons to:

- Use the toilet on entry to the pool change rooms
- Thoroughly wash themselves with soap before swimming to remove faecal and chemical contamination (cosmetics, deodorant and perspiration)
- Ensure children have regular toilet breaks
- Ensure infants who are not toilet-trained wear tight-fitting waterproof swimming pants or swimming nappies
- Ensure nappies are changed regularly, away from the pool in the change room. Nappies should be disposed of in a bin and then hands thoroughly washed.

There is overseas evidence that compliance with these hygiene practices has enabled lower chlorine usage because chlorine demand and the need for oxidation have been lowered. See section 8.5 for the *Healthy Swimming* program materials for pool operators.

6.7.2 Superchlorination

Superchlorination can be used to control chloramines. However if it is not performed properly it can result in more problems for the pool operator. Superchlorination should be carried out when the pool is closed and adequate ventilation must be provided to remove any volatile chloramines that may form. Regular superchlorination may be necessary, depending on the ammonia nitrogen concentration and its ratio to chlorine.

The aim of superchlorination is to achieve a condition known as breakpoint (see Appendix A), the point at which free chlorine is present with very little, if any, chloramine. Breakpoint reactions are dependent upon pH, temperature, contact time and initial concentrations of chlorine to ammonia and chlorine to ammonia nitrogen ratios.

Indoor swimming pools may have difficulty obtaining breakpoint and may require additional treatment using UV light, ozone, or the addition of other oxidisers such as hydrogen peroxide and potassium monopersulphate. Some pool materials may be adversely affected by high concentrations of chlorine. A pool chemistry expert should be consulted to ensure that superchlorination is carried out in a safe and efficient manner.

6.7.3 Shock dosing

(i) Chlorine dioxide

Chlorine dioxide can be used as a shock treatment for swimming pools and spa pools as it is an effective oxidiser and more effectively inactivates *Cryptosporidium* oocysts than hypochlorous acid. Chlorine dioxide does not form chloramines. The formation of chlorite and chlorate may cause adverse health effects and it is necessary to ensure these harmful chemicals do not accumulate. The World Health Organization recommends that the chlorite (ClO_2^-) concentration should not exceed 0.3 mg/L and a provisional guideline of 0.7 mg/L has been set for chlorate (ClO_3^-).

Chlorine dioxide should not be used in conjunction with ozone or an activated carbon filter as these combinations will increase the concentration of chlorite. Dilution with fresh water may be necessary to maintain acceptable water quality.

(ii) Potassium monopersulphate

Potassium monopersulphate can also be used to control chloramines in heavily used pools. These products lower the chlorine demand by oxidising ammonia and other pool contaminants. Care must be taken to ensure that potassium monopersulphate is not overused, because long-term use has been associated with skin irritation. Potassium monopersulphate interferes with the DPD reagent No 3, causing water samples to turn dark red. The monopersulphate is oxidised by this reagent and a false high total chlorine measurement is given. This effect usually ceases after 24 hours after which time total chlorine may be measured more accurately.

6.7.4 Ultra violet light treatment systems

Ultraviolet (UV) light treatment systems may be installed in indoor swimming pool circulation systems to lower chloramine concentrations. Medium pressure UV light systems which produce high intensity light between wavelengths of 180 to 400 nanometers (nm) are most effective at destroying chloramines because the chlorine to nitrogen bond is broken between a wavelength range of 245 and 340 nm. Medium pressure UV lamps are not affected by water temperature. Low pressure UV lamps with an electromagnetic spectrum between 185 and 254 nm are unsuitable for chloramine destruction although some are reported to destroy chloramines.

UV light systems provide additional disinfection by inactivating micro-organisms, especially protozoans such as *Cryptosporidium parvum*. Destruction of micro-organisms is greatest between the wavelengths of 240 and 280 nm and is thus another reason supporting the installation of UV light treatment.

UV light treatment systems do not produce a residual disinfection effect and must therefore be used with an approved residual disinfectant such as chlorine or bromine. There is also some concern that UV light treatment may increase disinfection by-products under some circumstances.

UV lamp sleeves need regular cleaning because they may continually foul with oils and greases such as cosmetics and sun screening lotions. Manual or automatic UV lamp wiping systems are usually provided in modern pool UV light systems for this reason. The latest medium pressure UV lamps also include the capacity to adjust UV intensity to the water's light transmission ability or clarity so that they operate at the highest output under heavy loading conditions and at the lowest output at night to save energy. This more effectively targets combined chlorine while prolonging lamp life. UV lamps have a useful life of approximately 12 to 18 months and should be replaced in accordance with the manufacturer's recommendations.

6.7.5 Ozone

Ozone is a powerful oxidant which is used to control chloramines and provide additional disinfection. Any residual ozone must be quenched before the water is returned to the pool to prevent it from de-gassing from the pool into the breathing zone of deeply breathing swimmers. A residual disinfectant such as chlorine or bromine must be reinstated after ozone quenching.

Ozone is produced commercially by discharging high voltage electricity (4,000 v to 30,000 v) through clean, cool, dry air or oxygen. This is known as the corona discharge method. Ozone may also be produced as a by-product by specific wavelength UV lamps. Corona discharge produces large quantities of ozone in comparison to the UV light method. Ozone's occupational threshold limit value is 0.1 mg/m^3 in air. At 1.0 mg/m^3 in air it is extremely hazardous to health.

Ozone is a short lived, unstable but powerful oxidising and disinfection agent and does not react with porcelain or glass. Ozone disappears quickly from water; a characteristic which is advantageous, but disadvantageous because it cannot be relied upon to provide continuous residual disinfection.

See 5.3.3 for information on the use of low dose ozone.

Where ozone is used in conjunction with bromine, an activated carbon filter bed is not required to quench the ozone, provided that there is always an excess concentration of bromide in the water. This ensures the complete destruction of residual ozone. This treatment system requires a highly skilled designer and operator to ensure safe operating conditions.

6.7.6 Granulated activated carbon filters

In some swimming pool installations, incoming source water is filtered using a granulated activated carbon (GAC) filter to adsorb ammonia. GAC filters are also used to filter ozone and sometimes organic materials. Unfortunately GAC filters also remove chlorine, which is expensive to replace.

6.7.7 Zeolite

Zeolites are porous volcanic materials and their properties vary according to geographical source. It is claimed that zeolites reduce the formation of chloramines by adsorbing ammonia and solid particles to 5 microns. Investigations are still being performed into the attributes of zeolite.

6.7.8 Ventilation – indoor

Adequate exhaust ventilation and fresh air are essential for efficient removal of chloramines and other air impurities. Chloramines, particularly trichloramine, are volatile, that is, they readily move from the water to the air. However, when the air becomes saturated with chloramine they will no longer be given off and can be re-dissolved into the same or other swimming pools in the same room. Pool covers, while preventing heat loss can also prevent chloramines from volatilising and being removed from the building.

There is a balance between losses of warm air, re-circulating warm air and off-gassing of chloramines. This balance needs to be determined without causing drafts and requires the expertise of suitably qualified ventilation professionals.

Recent articles suggest that there are associated health risks with poor indoor pool ventilation. In the absence of definitive studies this may be an emerging health issue.

CHAPTER 7

Design, construction and amenities

7.1 Overview and introduction

Public swimming pools and spa pools are designed to contain a large volume of water to enable swimming. A new public swimming pool should be equipped with an effective water circulation system, a water filtration system, and an automatic disinfectant dosing system.

Continuous non-automatic metered disinfectant dosing systems are more suited to low bather load and low risk pools such as motel pools where very low disinfection demand would be experienced. It is recommended that all high bathing load pools and variable bathing load pools should have automatic dosing systems.

All swimming pools and spa pools should be constructed according to the Building Code of Australia and recognising any appropriate Australian Standards / New Zealand Standards. Competition swimming pools also need to be constructed to satisfy the rules and regulations of the Federation Internationale de Natation (FINA – www.fina.org/project/index.php) All pools should comply with the NSW *Swimming Pool Act 1992* administered by local councils.

There are some common sense health and safety features for swimming pools:

- Clearly visible depth markings
- No sudden steep floor changes of greater than 1:15 in shallow areas to a depth of 1.6 m
- No projections into the pool
- Non-slip surfaces at depths less than 1.2 metres
- Recessed ladders and lane divider hooks
- Suctions and covers that are maintained in good working order
- The pool surrounds should be of a non-slip material, extend at least 1m from the pool, be graded away from the pool and drained to waste
- No overcrowding which could lead to safety issues
- Light pool colours which would not disguise a submerged body

7.2 Circulation and filtration

Effective circulation and filtration of swimming pool water is essential for clear, clean water. Pools with poor clarity and turbidity are more likely to contain higher numbers of micro-organisms because turbidity reduces disinfection efficiency and may shield micro-organisms from disinfection. Also, it is essential to clearly see the bottom of the pool in order to detect submerged or drowning people, particularly children. Water clarity (turbidity) can be measured and an upper limit of 0.5 nephelometric turbidity units (NTU) is recommended by WHO (2006).[2]

Efficient pool filtration and circulation systems need to be designed by an experienced professional water treatment plant designer and correctly installed. Well designed filtration ensures efficient removal of particulates (suspended solids) and effective distribution ensures application of residually disinfected water uniformly throughout the pool. Poor circulation leads to dead spots of poor quality water.

All of the water treatment plant must be specifically designed for the type of pool it is to serve. For example, a water treatment plant for a 25 m pool would be significantly different to that for a children's shallow pool.

Ideally, 75-80% of the pool water should be taken from the surface of the pool because it contains the highest concentration of pollutants. The remainder should be drawn from the bottom of the pool to remove grit and other matter that accumulates on the pool floor.

7.2.1 Surface water removal

Efficient removal of surface water is critical for maintaining water quality because surface water contains the highest concentration of pollutants from body fats, oils, sunscreens, sputum and windblown debris. Surface water removal occurs at deck-level or through overflow channels or skimmers.

All pool surrounds and concourse areas should be constructed of water impervious, non-slip materials and be graded away from the pool. A pool concourse should not be less than 1 m in width and be graded and drained to waste, not to the pool circulation system.

Deck-level (wet decks): Most modern pools incorporate deck-level surface water removal into their design. These systems are the most efficient at removing pollutants from pool surface water because the surface water continuously flows into the wet deck. To achieve this, the pool water must always remain at the same level as the wet deck. Wet decks have the added advantage of reducing wave rebound action and provide a stable water level. Excess water is stored in a balance tank and is utilised when needed and for backwashing.

Overflow channels (gutters): Overflow channels or gutters are more common in older pools built prior to the 1970s. Overflow channels collect surface water continuously from the pool in a sill like gutter structure. Similar to wet decks, water displaced by swimmers flows into the overflow channel. The overflow channel is connected to a drain. In some systems the excess water is stored in a balance tank which may be used for backwashing or topping up the pool when needed. Careful attention needs to be paid to the pool water level if a balance tank is not used as surface water removal may not be effective. Similarly, depending on design, wave action may render skimming less effective until the pool is relatively still.

Skimmers (skimmer box): These are small open ended boxes with a flap type floating weir and trash basket to trap floating debris. These act in a similar manner to overflow channels, but are considered unsuitable for public swimming pools because they have limited capacity to remove flotsam and do not cope well with variations in water level arising from displaced pool water. Skimmers are also less effecting during wave action and perform better when bathers are absent from the pool. **Skimmer boxes, although not recommended in public pools, must be designed and installed to prevent entrapment and disembowelment.**

Water features: The water used to supply water features should not be drawn from the distribution / circulation system. Water feature supply water should be drawn from the body of the pool and pumped directly to the water feature. The water feature water must be drawn from the pool using multiple suctions of a velocity of not more than 0.25 m/s. Each suction should be fitted with a vacuum device to ensure that bathers cannot be trapped.

Foot baths for bathers are not recommended as they are more likely to transmit infections than wash contamination from feet.

Pool circulation

At least 75-80% of the pool water should be taken from the surface of the pool and the remainder from the bottom. Bottom suction should be achieved using multiple suctions of a velocity of not more than 0.25 m/s (metres per second) and a minimum separation distance of 0.8 m. Deep-end suction outlets are considered essential and should be designed to prevent entrapment.

7.2.2 Bather load

Bather load is a measure of the number of bathers in the pool and is normally expressed as a Maximum Instantaneous Bather Load (MIBL). Before turnover, circulation rates and filtration rates can be considered, bather load must be determined. WHO (2006)[2] has adopted the Pool Water Treatment Advisory Group (PWTAG) methodology for determining turnover through bather load and circulation rate.[44]

Bather load is determined by the surface area of the pool required per bather and as a function of water depth. As water depth increases the greater pool surface area needed to swim. The MIBL also gives an indication of the amount of bather pollution being introduced into the pool. This pollution may vary according to the size of bathers as children have a much lower surface area than adults (assuming that all people toilet before entering the pool). To maintain water quality, comfort and safety, the design MIBL requirements should not be exceeded, Table 7.1 should be used as a guide where the design MIBL requirements have not been specified by the design consultant

Table 7.1: Maximum instantaneous bather load according to water depth

Water depth	Maximum bathing load
< 1.0 m	1 bather per 2.2 m^2
1.0 – 1.5 m	1 bather per 2.7 m^2
> 1.5 m	1 bather per 4.0 m^2

Source: PWTAG 1999[44] and WHO 2006[2]

7.2.3 Circulation rate and pool turnover

The circulation rate is the flow of water, measured in cubic metres per hour (m^3/h), to and from the pool through all the pipe work and treatment system. To calculate circulation rate PWTAG (1999) uses the formula of:

Circulation rate (m^3/h) = Maximum instantaneous bathing load (persons) $\times$ 1.7 (a constant)

Pool turnover is the time taken for the entire pool water volume to pass through the filters and treatment plant and back to the pool (WHO, 2006). This does not mean that all of the water will leave the pool and be re-circulated. Rather it is a measurement of the equivalent pool volume, as some of the pool water will not actually be recirculated. Turnover time is expressed in the number of hours to complete one turnover. The type, size and particularly the depth of the pool determine pool turnover time. Shallow wading pools and spas require a shorter turnover time as they are subject to more bather pollution per volume of water (bather load). Diving pools need a slower turnover time because there is a very low pollution to volume ratio.

There are four reasons for specifying minimum turnover rates:

- To ensure that there is sufficient water for effective distribution in the pool and adequate surface water velocity for the removal of surface contaminants
- To ensure that contaminated swimming pool water is returned to the water treatment plant with sufficient speed
- To ensure a large enough water treatment plant to effectively remove turbidity to achieve acceptable standards of clarity
- To ensure sufficient water disinfection.

The relationship between circulation rate and turnover is:

$$\text{Turnover period (h)} = \frac{\text{Water volume (m}^3\text{)}}{\text{Circulation rate (m}^3\text{/h)}}$$

When a turnover period is too long, disinfectant levels will decay and turbidity will increase. A faster turnover period allows greater control over disinfectant levels and turbidity. Because the bather load is a function of water depth, calculations of turnover can lead to step-wise calculations. The recommended pool turnover times as a function of water volume and circulation rates formulae have been derived by Stevenson and Associates (pers comm.) and are specified in Table 7.2.

It has been recommended by some swimming pool designers that where ultrafine filters are used, which filter pool water to 2 μm or less, that the turnover time in indoor swimming pools can be increased by 15% and outdoor swimming pools increased by 10%. The Stevenson formulae for pool turnover times are derived from the previous NSW Health 1996 guideline[45], together with PWTAG[44] and WHO[2] recommendations by removing the stepwise increments due to varying pool depth categories. No pool should have a turnover period longer than six hours.

Table 7.2: Recommended pool turnover times

Pool type	Maximum turnover time
Spa pools	20 minutes maximum
Stevenson formula for indoor swimming pools	(1.3 $\times$ depth) + 0.2 hours
Stevenson formula for outdoor swimming pools	(1.8 $\times$ depth) + 0.2 hours
Multiplier for indoor swimming pools where an ultrafine filter is used: 1.15	Multiplier for outdoor swimming pools where an ultrafine filter is used: 1.10

NOTES: Water playgrounds and splash pools are not included in the above calculations as they must be specifically designed. Where pools are greater than 4m deep they shall be calculated as a 4m pool.

EXAMPLE 1: The maximum turnover time for an indoor pool of 1.2 m uniform depth using an ultrafine filter is: ((1.3 $\times$ 1.2) + 0.2) $\times$ 1.15 = 2.0 hours

EXAMPLE 2: The maximum turnover time for an outdoor pool of 1.2 m uniform depth using a granular filter is: ((1.8 $\times$ 1.2) + 0.2) = 2.36 hours

EXAMPLE 3: The maximum turnover time for an outdoor pool of 1.2 m uniform depth using an ultrafine filter is: ((1.8 $\times$ 1.2) + 0.2) $\times$ 1.10 = 2.6 hours

There are many special pool applications where the methodology needs to be modified to account for: pool water features, bubble pools, waterslide splash pools, beach pools, pools with moveable floors, spa pools, shallow leisure pools, wave pools and hydrotherapy pools. Such pools need to be designed by experienced professional pool designers.

7.2.4 Water distribution – zonal and non-zonal

Calculations of water flow for each depth should be done separately, not on an average depth of the whole pool. This results in zonal distribution. To ensure that all areas of a pool are disinfected and filtered, no part of a pool should be further than 5.0 m from an inlet.

In applying the recommended turnover rates most pools will have varying flow rates that may result in a zonal water supply system. The volume of water to be circulated in any one zone is the volume of the pool zone divided by the turnover rate. Therefore the turnover (hours) is equal to the zone volume (m^3) divided by the circulation rate (m^3/h).

7.2.5 Separate plant for high risk pools

Because toddler pools, infant learn-to-swim pools and pools used by faecally incontinent persons are high risk pools in regard to *Cryptosporidium* and *Giardia* contamination, these pools should have their own circulation and treatment systems and be separate from other pool circulation systems.

7.2.6 Dye Testing

It is recommended that all new pools be dye tested so that the pool owner / operator / designer / engineer gains an understanding of the overall effectiveness of circulation patterns and identifies any possible dead spots.

7.2.7 Entrapment prevention

Swimming pools and spa pools must be designed to prevent entrapment. Relevant standards should be consulted.

7.2.8 Upgrading existing outdoor pools

Upgrading and refurbishing of existing outdoor pools often presents a dilemma for pool owners, particularly local councils with limited funding. Where it is not possible to upgrade to this Advisory Document, but funds are available to effect some improvements, attempts should be made to upgrade to the most economically feasible optimum design configuration. The following issues should be considered:

- Turnover should not be longer than 4 hours for depths less than 3 metres for a swimming pool and longer than 30 minutes for a spa pool
- Strategies should be developed to compensate for the lack of turnover. Such strategies could include:
  - A risk management plan to ensure that possible public health risks are minimised
  - Full automation of disinfection and pH processes
  - Limiting bather numbers
  - Elevation of minimum disinfectant concentrations
  - Improving filtration.

7.3 Filtration systems

It is a common misconception that all of the water in a swimming pool or spa pool will be filtered during one pool turnover. At the start of filtration the first flows will be dirty water and, as this water is filtered and returned to the pool, it will mix with and dilute the remaining dirty water. Filtration is accomplished by consecutive dilution which relies on continuous turnover and dilution to remove impurities. About 67% of the filterable material is removed on the first turnover and then in accordance with Table 7.3.

Table 7.3: Consecutive dilution of a pool

No. of turnovers	Filterable suspended solids removed (%)
1	67.0
2	86.0
3	95.0
4	98.0
5	99.3
6	99.7
7	99.9
10	99.99

In reality, the pool will be in use and contaminants will be continuously added while being continuously filtered. Therefore the contaminants will reach equilibrium with turnover rates and remain fairly constant according to the bathing load. The more rapid the turnover rate the less time to reach equilibrium and the lower the contaminant level as shown in Table 7.4.

Table 7.4: Turnover equilibrium times

Turnover (hours)	Days to reach equilibrium	Filterable suspended solids removed (%) (Original 100%)
48	19	155
24	9	58
12	4	16
8	3	5
6	2	2

For these reasons filtration should never be relied upon to remove live micro-organisms, particularly *Cryptosporidium* and *Giardia,* from pool water.

It is not the intention of this Advisory Document to recommend specific flow rates, filtration rates and pipe sizes as only turnover periods are specified. A professional pool designer should be engaged to design filtration systems according to the pool type, size and the anticipated bather load. Other factors such as budget, maintenance and space requirements may also determine the type of filtration system to be installed.

There are three main types of filters: element (cartridge), granular (sand) and ultra fine (diatomaceous earth). A comparison of some of the parameters of these filters may be found in Table 7.5.

7.3.1 Element filters (cartridge filters)

Element filters are able to filter to 7 µm (micrometres or microns). However, because of their short life span and their limited capacity to cope with large flows, they are only suitable for small, low bather load pools. Some pool engineers will not recommend element filters for public pools.

7.3.2 Granular filters (typically sand filters)

Granular filtration, when used with a flocculant, is a very efficient method of filtration provided the filters are specified by a water treatment engineer and that air scouring is used when appropriate for backwashing the filter.

Granular filtration can be categorised according to filtration flow rates:

- Low rate (gravity) up to 10 m^3/h: have a large footprint and were commonly associated with swimming pools built before 1990. They are efficient when used with a flocculating agent and often utilise an air scour backwash.
- Medium rate (pressure) 11-30 m^3/h: can filter to about 7µm using a suitable coagulant. These filtration systems are most common in large commercial pools and the use of a suitable flocculation agent significantly improves efficiency.
- High rate 31 to 50 m^3/h: are not well suited to heavy-use public swimming pools. They may not be efficient at removing particles even when flocculation agents are used and need to be well designed to cope with higher velocity flows.

Coagulation/flocculation: Coagulants are filter aids for the additional removal of dissolved, colloidal and suspended matter by coagulation and then clumping together to form a flocc. A filter more easily captures a flocc.

Aluminium-based flocculents include:

- Aluminium sulphate (ALUM) – filter surface blanket type flocculent;
- Polyaluminium chloride or aluminium hydroxychloride (PAC) – depth of filter bed flocculent;
- Polyaluminium sulpho silicate (PASS) – depth of filter bed flocculent;
- Sodium aluminate – filter surface blanket type flocculent.

Aluminium-based flocculants operate best between a pH of 6.5 – 7.2 and where total alkalinity is greater than 75 mg/L calcium carbonate ($CaCO_3$). Pool pH should ideally be maintained between 7.2 and 7.6. Polyelectrolytes such as PAC and PASS produce tough flocc (which is more stable than ALUM floccs) and are capable of flocculating bacteria and algae for more efficient removal. Flocculants should be dosed continuously in accordance with the manufacturer's specification and never hand dosed (unless commissioning a new pool with dirty water).

PAC and similar polyelectrolytes are dosed as micro-feeds related to specific filter flows on a continuing basis. ALUM floccs are generally dosed at the beginning of filter cycles as they form flocc blankets on the filter bed surface. Generally, ALUM floccs are not suitable for filter flow rates exceeding 10m^3/h because they are driven into the media body and may be difficult to backwash clear or will coagulate on the pool floor and internal surfaces of pipes.

7.3.3 Ultrafine filters incorporating diatomaceous earth filters

Ultrafine pre-coat filters (UFF) provide excellent particle removal efficiencies as they can filter to 1-2 µm. This is effective for the removal of *Cryptosporidium* oocysts. UFF is therefore recommended for all high-risk pools where the risk of *Cryptosporidium* contamination is greater.

UFF rely on a replaceable filter medium such as diatomaceous earth (celite) and perlite, which is replaced after each backwash. The effectiveness of filtration is dependent upon filter media, hydraulic loading and maintenance.

Table 7.5: A comparison of some filter types

Criteria	Filter type		
	Ultrafine	Medium granular	Element
Common filter sizes	Up to 80 m^2	Up to 10 m^2	Up to 20 m^2
Design filter flow rate	3-5 $m^3/m^2/h$	25-30 $m^3/m^2/h$	1.5 $m^3/m^2/h$
Cleaning flow rate	5 $m^3/m^2/h$	37-42 $m^3/m^2/hr$	Not applicable
Cleaning	Periodic disassembly and septum cleaning	Backwash and rare sand replacement	Manual, hose down
Average wash water	0.25 m^3/m^2 filter	3.0 m^3/m^2 filter air scour 3.3 m^3/m^2 filter water only	0.02 m^3/m^2 filter
Filter cleaning period	3 weekly (typically)	Weekly (typically)	Weekly or less (typically)
Filter aid	None	Micro-flocculants are recommended	None
Cleaning implications	Backwash tank with separation zone for used filter media. Disposal of filter media and sludge waste. Trade Waste Agreement with a discharge rate of 2 L/s	A backwash tank. Trade Waste Agreement with a discharge rate of 2 L/s	A hose-down and waste drain facility is required
Particulate collection	Surface	Depth	Surface
Particle removal	1-2 µm	10 µm; 7µm with flocc	5 µm
Use	All pools	All pools	Spas – small
Recommended maximum filtration rate	5 $m^3/h/m^2$	30 $m^3/h/m^2$	1.5 $m^3/h/m^2$

Source: Modified from WHO (2006)[2]

7.4 Maintenance of swimming pools and spa pools

Reliable pool operation depends on regular maintenance of filtration equipment, probes, electrical and hydraulic equipment. All swimming pools and spa pools should be maintained according to the manufacturer's specifications. Table 7.6 outlines some of the maintenance requirements that are required for the proper operation of public swimming pools and spa pools.

7.5 Change rooms, pool hall and amenities

7.5.1 Floors, walls and change areas

Floors within change rooms, bathrooms and toilets should be coved at corners, graded and drained. Matting which can be easily cleaned and sanitised (such as PVC) should be used within change rooms and shower rooms to prevent the transmission of fungal infections such as tinea. Matting materials made from natural or woven materials should not be used. Patrons should be encouraged to wear sandals or thongs to limit contact with potentially contaminated wet change room floors.

Benches should be constructed of smooth impervious material and, if timber is used, it should be maintained by a lacquer or paint, which is easy to clean. All floors, walls and ceilings should be light in colour. Lockers should be inspected and cleaned weekly.

7.5.2 Light and ventilation

Adequate artificial and natural lighting and ventilation should be provided in accordance with the Building Code of Australia and relevant Australian Standards.

Adequate fresh make up air for indoor pools is necessary to dilute volatile air contaminants. Where chlorine is used as a disinfectant, inadequate ventilation results in the build up of volatile combined chlorine in the air. This build up can condense onto surfaces causing corrosion of stainless steel and other building fabrics.

Where a cooling tower is provided in water cooled ventilation systems, it should be registered with the local authority and must comply with the microbial control provisions of the *Public Health Act 2010* and *Public Health Regulation 2012,* which can be accessed via: http://www.health.nsw.gov.au/environment/legionellacontrol/Pages/default.aspx

7.5.3 Showers

Ideally, swimming pool centres should be designed to encourage all people to toilet and then shower before entering a swimming pool. To facilitate this, an adequate number of showers should be located in the dressing room in positions where patrons have to pass by them before entry to the pool area.

Table 7.6: Minimum maintenance requirements of swimming pools and spa pools

Plant	Maintenance
Balance tank	Balance tanks need to be cleaned annually to remove any debris, mud and organic matter. Balance tanks, which do not drain to waste, need to be pumped out.
Foot valve	If fitted, the foot valve should be serviced annually.
Supply (filtered) water inlets	Pool supply water inlets and surrounding tiles should be checked after each shut down for damage and compliance with the specifications. It is important to check the diameter of the supply return inlet because obstructions will reduce flow rates (increase turnover times). Reduced flow rate could lead to poor water quality.
Return (soiled) water outlets	Outlet screens should be cleaned daily. Gutters, wet deck outlets and skimmer boxes should be inspected weekly. Similar to supply fittings (inlets), any obstruction will increase turnover times and may lead to poor water quality. More particularly, blocked screens will starve the filter plant and pumps of water.
Cleaning filters: backwashing	The filter should be backwashed on a regular basis or when indicated by loss of head gauges (if fitted) or a reduction in the rate of flow measured by a flow meter. Waiting for an observable flow reduction will be too late. Pool filters should be backwashed weekly regardless of head loss because the entrapped oxidised body fats and sun screens are not detained but only restricted from travelling through the filter bed. They may build up with little evidence of head loss but will ultimately penetrate the filter bed. Preferably, backwashing should continue until the water runs clear (or only slightly cloudy). In a closed system (where the backwash effluent is not visible) a reduction in the head loss after each backwash should indicate adequate cleaning of the filter(s). If the pressure level is increasing after each backwash, a longer backwash time may be required. Head loss should always reduce after backwashing. A filter which does not show reduction should be investigated.
Cleaning filters: sand inspection and maintenance	Inspect condition of filter yearly. If the sand is unclean (indicated by the presence of mud, grease or alum balls) it is usually recommended to replace the dirty sand layer with clean sand. Sand may need to be visually inspected every 5 years depending on filter performance.
Cleaning filters: ultrafine filters (UFF)	UFF media should be replaced when backwashing is undertaken. The media should be re-generated weekly. If the pool is implicated in a *Cryptosporidium* outbreak the filter should be backwashed immediately.
In line filters or strainers	The main hair and lint strainer should be checked daily and cleaned when required.
Pool suctions	All pool suctions should be checked every three months.
Suction cleaning	The frequency of suction cleaning to remove large contaminants depends upon the bather loads and usage conditions of the pool. A plan of management should be developed accordingly. Under normal operating conditions, suction cleaning may be required two or three times a week or once per week when the pool is not heavily loaded. Large items such as rubber bands, hair clips and leaves should be removed with a net. It is recommended that larger pools use an automatic pool cleaner each night.
Automatic control probes	The pH and oxidation-reduction potential (ORP) probes need to be calibrated and serviced to remove any scale that has developed. They should be inspected, cleaned and calibrated at minimum six monthly intervals. Electrical inspection should be conducted yearly by a licensed electrician.
Main circulation pumps and motors	The main circulation pumps and pump motors should be serviced annually and checked regularly. All maintenance should be in accordance with the manufacturer's specification. Ideally multiple spare pumps should be available in case of a failure.
Chlorine pump/ chlorinator	The chemical dosing system including any pumps (chlorinator) should be serviced annually and chlorine pumps with an oil reservoir checked weekly. Upgrading to a larger capacity output system to cope with superchlorination needs due to *Cryptosporidium* contamination should be considered.
Cleaning	Daily cleaning of any dirty water marks (biofilm) around the water line is recommended to prevent the harbourage of any pathogenic micro-organisms. Regular superchlorination or oxidation is recommended to remove any biofilms within pipes, fittings and filters.
Electrical	Electrical inspection should be performed annually by a licensed electrician experienced with swimming pools.

Soap should be provided in all showers and signs should be erected to require showering before swimming. Cleaning and disinfection of shower floors should be performed daily and scrubbing to remove soap and dirt accumulation should be undertaken weekly. Most importantly all tap ware, shower stalls and basins should be cleaned and disinfected regularly to inhibit cross contamination.

Where a warm water system is installed, the local authority should be advised and consulted about Legionnaires' disease control. The NSW Health website should be visited to consult the *Public Health Regulation 2012* and the *NSW Code of Practice for the Control of Legionnaires' Disease*.
http://www.health.nsw.gov.au/environment/legionellacontrol/Pages/default.aspx

7.5.4 Hand basins

Hand basins should be located adjacent to toilets with an adequate supply of soap and paper towels or air hand drying machines. Communal towels should not be provided. All tap ware and basins should be cleaned and disinfected regularly to inhibit cross contamination.

7.5.5 Toilets (water closets)

Toilets should be located in close proximity to the dressing room and adjacent to the showers. Toilets should be easily accessed from the pool concourse to encourage regular toileting. Toilet numbers should be in accordance with the Building Code of Australia.

Children in particular, as well as adults, should be encouraged to use a toilet prior to swimming. Toilets should be provided with an adequate supply of toilet paper and maintained clean at all times. Lidded sanitary disposal bins for the disposal of sanitary napkins and tampons should be provided in the women's bathrooms. The toilet should not be used to dispose of sanitary products or hand towels.

All tap ware, pans and basins regularly cleaned and disinfected to minimise cross contamination.

7.5.6 Baby nappy change / parent facilities

Babies' nappies should not be changed adjacent to the pool. Comfortable baby nappy change facilities should be provided in close proximity to the toddlers' pool. Babies wearing nappies should be prohibited from bathing as the risk of faecal contamination is too great. Children who are not toilet trained should wear specially designed bathing pants before pool entry. All tap ware, change tables, baths, and basins should be cleaned and disinfected regularly to inhibit cross contamination.

7.5.7 Waste removal (garbage)

Adequate garbage bins should be provided particularly in the spectator and lawn areas, and adjacent to the kiosk. All receptacles used for the storage and removal of waste should be cleaned and sanitised regularly to prevent attracting vermin and rodents. Bin liners will assist in maintaining bins clean. Bulk garbage should be stored in a cool, bunded, secure area and should preferably be located under cover. The storage area should be maintained in a clean condition and free from vermin.

Yellow sharps disposal containers conforming to Australian Standards should be located in all toilet areas.

7.5.8 Storage of hazardous and dangerous chemicals

The NSW WorkCover Authority regulates the storage and handling of dangerous goods through the *Work Health and Safety Act 2011 and Work Health and Safety Regulation 2011*. WorkCover Authority should be consulted to obtain any information with regard to the storage and handling of swimming pool and spa pool chemicals. (See Section 5.4)

7.5.9 Water temperature

Where spa pools are heated, the temperature must never exceed 38°C. Signs should be displayed restricting bathing to 20 minutes in high temperature pools warning of the dangers of heat stress.

Overheating of the body can cause heat illness. The body has no mechanism to warn of overheating. In saunas and high temperature pools such as spas dehydration, heat exhaustion and fainting may occur. On entering a heated pool or sauna, the skin blood vessels dilate to help lose heat and keep the body cool. The heart pumps faster and heart rate increases. If there is insufficient blood to the brain, there is a lack of oxygen and dizziness and fainting may result. Deaths have resulted when alcohol has been consumed and the body subjected to heat stress.

Heat exhaustion is caused by a loss of water and electrolytes. Any sustained muscular exertion can cause loss of water and electrolytes. It is relieved by rest, fluid and electrolyte (salt) replacement. Children and those with medical conditions, especially heart conditions, are particularly at risk and should seek medical advice before using spas or saunas.

Spa pool heat warning: Bathing for longer than 20 minutes in hot pools and spas may cause heat illness. Parents of children under the age of 6 years, persons with medical conditions and pregnant women should seek medical advice before using a heated spa pool.

7.5.10 Towel and costume hire

Towel and costume hire is not recommended but where provided separate storage facilities should be provided for clean and used costumes and towels. Used costumes and towels should be laundered as soon as possible, using commercial laundry facilities.

7.5.11 First aid

First aid equipment and a sick bay should be provided as appropriate. Cardio-pulmonary resuscitation signage must be provided in accordance with the Royal Life Saving Society, St John's Ambulance Australia and local authority requirements.

7.5.12 Shade

The use of an outdoor swimming pool complex by patrons exposes them to harmful UV radiation. Shade should be provided at all outdoor public swimming pools to protect the public. Guidelines for the provision of shade are available from the Cancer Council at:
http://www.cancercouncil.com.au/reduce-risks/sun-protection/

7.5.13 Glass

All glass and glass products should be banned from public swimming pools and spa pools. Clear broken glass cannot be seen under water. Water samples should be taken in plastic beakers or sampling containers.

7.5.14 Kiosk

Kiosks must comply with the Food Standards Code administered by the NSW Food Authority and local authorities:
http://www.foodauthority.nsw.gov.au/

CHAPTER 8

Cryptosporidium risk management

8.1 Overview

The purpose of this chapter is to provide best practice guidance on prevention and control measures to reduce public health risk associated with *Cryptosporidium* contamination of swimming and spa pools. This chapter is relevant for similar disinfectant resistant micro-organisms, such as *Giardia*. For general information on microbiology see Chapters 2 and 3.

8.2 Epidemiology of cryptosporidiosis

Cryptosporidium parvum is the parasite responsible for cryptosporidiosis, a diarrhoeal illness in humans, which can also occur in a variety of animals such as cattle and sheep. In a person with the infection, the parasite invades and multiplies in the gastro-intestinal tract, causing illness and producing oocysts, the infective form of the parasite. Oocysts are excreted in faeces into the environment where they can survive for a many months.

Cryptosporidiosis transmission is by the faecal-oral route, including person-to-person, animal-to-person, waterborne and foodborne transmission. Animal droppings and human faeces containing oocysts may easily contaminate hands. Good personal hygiene practices are important. Oocysts are also deposited from animals in soil, water and food.

The first symptoms of cryptosporidiosis may appear 1 to 12 days after a person ingests the infective oocysts. Symptoms of the disease usually include profuse watery diarrhoea, abdominal cramps, fever, nausea and vomiting. These symptoms may lead to weight loss and dehydration. Some people with the infection may not have symptoms, yet excrete oocysts in their faeces. **There is no specific treatment for cryptosporidiosis.**

People with healthy immune systems usually have symptoms for one to two weeks and then recover fully. After symptoms subside, they may still continue to pass *Cryptosporidium* oocysts in their faeces for several days and therefore may still spread the disease to others.

Those with a weakened immune system, may have cryptosporidiosis for a longer period of time. In some cases the illness can be serious or even life threatening. People with compromised immune systems should discuss with their doctor their risk of getting cryptosporidiosis, including swimming at public pools and spas, and their need to take precautionary measures. Examples of people with weakened immunity include people with HIV, cancer and transplant patients on immunosuppressive drugs and people with inherited diseases affecting the immune system.

A review of the outbreaks of cryptosporidiosis associated with swimming pools shows that most occur in pools following faecal accidents by infants who are not toilet trained. The majority of other illnesses transmitted in swimming pools and spa pools are associated with poor disinfection.

The health risk of bathing in a pool contaminated with *Cryptosporidium* is directly related to the organism's characteristics, transmission and the epidemiology of the disease. Infective oocysts are resistant to standard levels of chemicals used in pool disinfection and are unlikely to be efficiently removed by a pool filtration system because of their small size and the lengthy time taken during the process of consecutive dilution (see Section 6.3).

8.3 Control measures and strategies

To reduce the risk of *Cryptosporidium* entering a pool, it is recommended that pool operators prepare a risk management plan with strategies to prevent the introduction of *Cryptosporidium* into pools and implement control measures to inactivate *Cryptosporidium*.

Risk assessment should address the following risk management areas:

- Swimmer hygiene practices
- Education
- Operational control and maintenance
- Sampling.

This is expanded in the following sections.

8.4 Swimmer hygiene practices

The single most effective method to prevent the transmission of *Cryptosporidium* in swimming pools is to stop oocysts from entering the pools in the first instance. This is done by improving swimmer personal hygiene practices. There are two priority areas:

- Personal hygiene
- Awareness of infants who are not toilet trained

8.4.1 Personal hygiene

People, particularly children, who have had diarrhoea within the previous two weeks, should not enter a pool. Many children's learn-to-swim centres have adopted the sensible policy of offering catch-up lessons when children have had vomiting, diarrhoea or conjunctivitis in the previous 7 days. Parents are asked to sign a declaration that their child has not been sick with vomiting, diarrhoea or conjunctivitis in the previous 7 days. Parents with healthy children are pleased that such a protective measure has been adopted. An example of such a form follows:

All patrons should be encouraged to:

- Use the toilet before entering the pool
- Shower and wash thoroughly all over with soap before entering the pool
- Avoid swallowing pool water as it may contain pathogenic micro-organisms

Basic hygiene facilities

- Soap dispensers should be installed next to the showers and hand basins.
- Hand-dryers or disposable hand towel dispensers should also be installed and maintained.
- Nappy changing facilities and bins for soiled nappies should be provided in a room adjacent to and accessible from the toddlers' pool.
- Hand washing posters.

8.4.2 Awareness of infants who are not toilet trained

To assist with the control of *Cryptosporidium*:

- Infants who are not toilet trained should have their water activities restricted to the toddlers' pool (where possible)
- Appropriate bathing attire should be worn at all times otherwise swimming should be prohibited
- Infants who are not toilet trained should wear tight fitting waterproof pants or swimming nappies at all times
- Swimming nappies should be changed in change rooms and not at the poolside

To enable us to have the highest level of sanitisation in our pool, all parents / guardians must sign this declaration before your child's lesson.

HAS YOUR CHILD BEEN SICK WITHIN THE LAST 7 CONSECUTIVE DAYS WITH VOMITING, DIARRHOEA OR CONJUNCTIVITIS? If yes, do not have a lesson today and we will give you a catch-up lesson when your child has not been sick for 7 consecutive days.

Date	Child name	Parent / guardian name	Yes	No	Signature

- Hands should be thoroughly washed with soap after changing swimming nappies
- Soiled nappies should be disposed of in bins provided
- Toddlers should be encouraged to use the toilet frequently

8.5 Education

Education of both the public and pool staff is essential in minimising the transmission of Cryptosporidiosis and fulfils part of the pool management's duty of care to its patrons. Because there is growing community awareness of *Cryptosporidium,* it is important to reinforce educational messages about personal hygiene.

NSW Health has developed educational resources to assist pool operators in preventing C*ryptosporidium* contamination of swimming pools. The following materials have been developed and are available from Public Health Units, Councils and on the NSW Health website at:
http://www.health.nsw.gov.au/environment/publicpools/Pages/default.aspx

Education for members of the public: The 2007 *Clean Pools for Healthy Swimming* campaign allowed production of the following brochures and posters.

- The Clean Pools for Healthy Swimming brochure. Available at: http://www.health.nsw.gov.au/pubs/2007/Clean_Pools.html
- The Steps to Healthy Swimming poster. Available at: http://www.health.nsw.gov.au/pubs/2007/Healthy_Swimming.html

Education for pool operators

- *Cryptosporidium* contamination response plan. Available at: Faecal accident response plan (loose stool in a pool) Available at: http://www.health.nsw.gov.au/environment/publicpools/Documents/cryptosporidium-notification-response-plan.pdf
- Faecal accident response plan (solid stool) Available at: http://www.health.nsw.gov.au/environment/publicpools/Documents/faecal-incident-loose-stool-response-plan.pdf

Clean Pools for Healthy Swimming brochure

Steps to Healthy Swimming poster

- Faecal accident response plan (loose stool). Available at: http://www.health.nsw.gov.au/environment/publicpools/Documents/faecal-incident-loose-stool-response-plan.pdf
- Accident response plan (vomit in pools) Available at: http://www.health.nsw.gov.au/environment/public pools/Documents/vomit-incident-response-plan.pdf
- Hard surface accident response plan (concourse, bathroom floors and pool surfaces) Available at: http://www.health.nsw.gov.au/environment/publicpools/Documents/hard-surface-incident-response-plan.pdf

The following educational strategies are also recommended as part of pool management:

- Ensure all pool staff are fully trained in pool/spa operational procedures
- Ensure that all pool staff are empowered to act immediately on incidents and behaviour which may cause contamination (e.g. infants with unsuitable swim wear, or patrons who may present a risk such as those who are incontinent or indicate they have had a diarrhoeal illness)
- Ensure patrons are aware that management will reserve the right to prevent patrons from swimming if there is reason to believe that they may cause a risk to other swimmers. Patrons need to be assured that management is keen to protect their health and that of their children
- Provide public information about the risks of spreading cryptosporidiosis. Methods for providing information could include information on noticeboards and distribution of the NSW Health *Clean Pools for Healthy Swimming* brochures to parents with swim school enrolments
- Display the NSW Health *Steps to Healthy Swimming* poster.

New pools

Consideration should be given to designing amenities so that all patrons have no choice but to walk through toilet and shower areas before gaining access to the pool. To encourage showering, warm showers with soap should be provided with temperature control devices to prevent scalding.

8.6 Operational control and management

Additional management strategies and policies should be developed to suit individual pools and be consistent with this Advisory Dociment. The following could specifically be considered:

- Circulation and filtration systems should be maintained to provide maximum filtration efficiency and run 24 hours a day
- Pool water disinfectant levels should be maintained in anticipation of bather numbers such that disinfectant concentrations always remain above the minimum recommended levels specified in Schedule 1 of the Public Health Regulation 2012
- Regular backwashing and superchlorination is important for the maintenance of good water quality and the prevention of biofilms in the circulation system
- All pools should be regularly cleaned
- NSW Health Response Plans for responding to potentially infectious accidents and notifications of cryptosporidiosis should be followed
- Pool water quality should be regularly tested on site in accordance with Chapter 5
- Samples for bacteriological analysis should be regularly submitted to a National Association of Testing Authorities (NATA) accredited laboratory according to Chapter 3.

NOTE

Bacteriological testing does not include testing for *Cryptosporidium;* however, the presence of *E. coli* is an indicator of possible faecal contamination. Note that *Cryptosporidium* has been detected in the absence of bacterial indicators (see section 8.6.2)

8.6.1 Barriers used in pool operations

Barriers are mechanisms used to prevent transmission of any disease from its source to a susceptible host. Barriers can include source control, cleaning and disinfection and pool closure. Two main barriers used in normal operating practices to minimise the transmission of micro-organisms to swimmers are:

- Filtration
- Disinfection

(i) Filters

Ultrafine filtration (UFF) is capable of removing *Cryptosporidium* oocysts. UFF however, cannot be relied upon as a control measure since it takes time to filter all pool water and some pool water will not be filtered because of circulation problems, dead spots and the principle of successive dilution (see Section 6.3). Where pools are being upgraded, separate circulation and treatment systems for hydrotherapy pools and toddler pools using UFF is essential. Upgrading of any hydraulic system to ensure good circulation of pool water should be considered.

> **Separate circulation systems**
> Separate circulation systems should be installed for toddler pools, hydrotherapy pools and other high-risk pools. Where separate circulation systems are installed bulk water should not be fed from one system to the other through balance tanks to avoid cross contamination.

(ii) Disinfection

Routine disinfection procedures, on their own, are not sufficient to quickly destroy *Cryptosporidium* oocysts unless a pool is shock dosed with chlorine. While chlorine and bromine at the recommended levels will eventually kill the oocysts over many days or even weeks, assuming no further contamination, the time lag is insufficient to adequately protect swimmers from infection.

- **Ct shock dosing – to inactivate *Cryptosporidium* oocysts**: Following notification of two or more cases of cryptosporidiosis that are linked in time to a public swimming pool, the pool should be Ct shock dosed to inactivate the *Cryptosporidium* oocysts. To achieve inactivation a pool should be shock dosed with a high concentration of chlorine over a long period of time to achieve a *Ct* (concentration x time) value of 15 300. (see section 4.3 for an explanation of Ct values).
  - A Ct value of 15 300 achieves a 4 Log (99.99%) reduction of oocysts. Examples are by dosing a pool with 10 mg/L of free available chlorine for 26 hours, 20 mg/L of free available chlorine for 13 hours, or 30 mg/L for 8½ hours (or other corresponding dose). A dose needs to be selected that will not adversely affect pool finishes, fittings and equipment while ensuring a suitably swift inactivation rate.
  - Chlorine dioxide may also be used to inactivate *Cryptosporidium* oocysts using a Ct value of 70 to inactivate 99.99% of oocysts (4 Log reduction). The circulation and filtration system must be operated during this time.
  - An oxidation-reduction potential (ORP) value of 865 mV for 30 minutes or 800 mV for 24 hours will also achieve a 4 Log (99.99%) reduction of *Cryptosporidium* oocysts.

- **Superchlorination:** Regular superchlorination should be practised as a maintenance procedure as it:
  - allows the pool to recover oxidation and disinfection while there is no contamination entering the pool
  - aids filtration, by clarifying and polishing of the pool water
  - destroys biofilms which may harbour pathogenic micro-organisms
  - inactivates *Cryptosporidium* oocysts.

Regular superchlorination should be performed when swimmers are not present (usually overnight) for an eight-hour period. Ideally superchlorination should be linked to the frequency of backwashing. Superchlorination usually requires approximately 6-8 mg/L (maximum 10 mg/L) of chlorine or ten times the combined chlorine concentration. A higher shock dose may be required for pools heavily polluted with chloramines and to remove biofilms.

8.6.2 Water sampling for *Cryptosporidium*

Water sampling for *Cryptosporidium* is not recommended unless a joint decision is made between the pool operator and NSW Health. Test methodologies are based on a 100 litre water sample and are very expensive. Testing only represents the status of the water at the time of sampling. Negative results may give a false sense of security and there is a long time delay before results are received. Also, the primary tests do not determine whether any oocysts detected are viable and able to cause infection.

CHAPTER 9

Pool designer and operator competencies

9.1 Overview

Modern swimming pools and their associated equipment are a complex and costly infrastructure investment. It is essential therefore that swimming pools be designed, commissioned, operated and maintained effectively and efficiently to ensure a long serviceable life.

Pool operators should be competent in all areas of water treatment and quality. They should also be competent with a range of matters like occupational health and safety, business operations, financial management, customer relations, and staff and recruitment procedures. For this reason all public swimming pool operators should undertake a course which includes all managerial and operational matters.

9.2 Pool designers

Swimming pool water treatment plants should be designed by experienced engineers / architects who are suitably qualified in the field of water treatment engineering, hydraulics or similar disciplines. Pool structures should be designed by suitably qualified and experienced structural engineers.

9.3 Operator competencies

Appendix 3 of Practice Note 15 (Water safety), issued by the Division of Local Government:
http://www.dlg.nsw.gov.au/dlg/dlghome/documents/PracticeNotes/Water_Safety_Oct_2005%20.pdf

lists the appropriate competencies for aquatic operations at the management level, the operations level and the supervisor level. Appendix 2 of the same document, for pre-defined water facility categories, lists areas of expertise, qualifications and professional development of staff.

9.4 Formal operator qualifications

Formal swimming pool operator qualifications are attained through the completion of units / modules of study delivered by Registered Training Organisations (RTOs) such as the NSW Department of Technical and Further Education (TAFE). RTOs and the units / modules of study must be recognised (accredited) by the Australian Skills Quality Authority. There are private RTOs that also offer accredited training courses. Operators should continually seek to develop their professionalism through attendance at appropriate conferences and short courses.

9.5 Pool safety qualifications

Pool safety courses are offered by The Royal Life Saving Society Australia (http://www.royallifesaving.com.au). It is also important to have a current Pool Lifeguard Certificate and a current approved First Aid Certificate. These requirements are mandatory for municipal pools (See Practice Note 15).

CHAPTER 10

Health risk management planning

10.1 Overview

Public pool managers depend on providing safe and comfortable facilities to their customers. Risk management is a tool which allows pool managers to minimise and even eliminate harmful situations at swimming facilities. This chapter develops a risk management framework which can be applied to public swimming pool management.

10.2 Public health risk

Risk is the likelihood of the occurrence of some adverse event, or in the case of public health, the risk of either disease transmission or the occurrence of some other health related event. For the purposes of public health risk analysis, disease transmission occurs when there is a source of disease or contamination, a transmission pathway or exposure route exists and there is a susceptible host (see Chapter 2, Section 2.3).

Contamination source + Transmission pathway + Susceptible host = Disease

For a public health risk to occur all three factors must be present. If just one of the factors is absent then disease transmission will not occur. Normally, risk management attempts to remove the transmission pathway through disinfection of pool water. For example, because of resistance to disinfection, *Cryptosporidium* needs to be controlled at the source. The only way to ensure susceptible hosts are protected is to exclude them from swimming in a public pool. This approach may be the only option for people who are highly susceptible to cryptosporidiosis.

10.2.1 Risk identification

Risk identification involves isolating and naming each type of hazard. It is appropriate to identify risk in the categories of source, transmission pathway and susceptible host. Each category may be divided into subcategories. A framework therefore starts to develop through the creation of the first column (Table 10.1).

Table 10.1: Risk identification column of the risk management framework

Identified risk
1. Contamination source - Identified risk - Identified risk - Identified risk - Identified risk
2. Transmission pathway - Identified risk - Identified risk
3. Susceptible host - Identified risk - Identified risk

10.2.2 Risk assessment / characterisation

Once a hazard has been identified, it is assessed as low, medium or high risk in two main ways:

- The likelihood or chance of the adverse public health event occurring;
- The magnitude of the adverse health event and the impact of its consequences.

A combination of the likelihood and impact can be used to determine priorities by using the risk priority table (Table 10.2). From left to right in the risk priority table headed *Likelihood,* the likelihood of an outbreak is assigned a value of high, medium or low. On the right column headed

Table 10.2: Risk priority table

Likelihood	Low	Medium	High	***Impact***
PRIORITY	MEDIUM	HIGH	HIGH	**High**
	LOW	MEDIUM	HIGH	**Medium**
	LOW	LOW	MEDIUM	**Low**

Increasing priority

Impact, the impact of an outbreak is assigned a value of high, medium or low. The two values are then used to select a corresponding priority box and its value of high, medium or low priority.

For example, the likelihood of an outbreak of cryptosporidiosis (the disease caused by *Cryptosporidium parvum*) may be medium because learn-to-swim classes for toddlers who are not toilet trained are held twice a week. The impact could be high as it could be debilitating for those who become ill, and devastating for the pool business for a few weeks when the community learns of the outbreak attributable to the pool. Therefore this risk can be assessed as:

- *Likelihood* – Medium
- *Impact* – High
- *Priority* – High

A second column can then be built into the framework based on the risk priority, known as risk assessment (Table 10.3).

Table 10.3: Risk assessment column of the risk management framework

Identified risk	Risk assessment
1. Contamination source	
1.1 People	
Identified risk	Likelihood – Impact – Priority =
1.2 External contamination	
Identified risk	Likelihood – Impact – Priority =
2. Transmission pathway	
Identified risks	
3. Susceptible host	
Identified risks	

10.2.3 Risk management plan

Risk management is the process of developing strategies, policies and procedures to lessen either the likelihood of the risk, the impact of the risk or both. Risk management adds the third column to the framework.

A rudimentary risk assessment / management framework has been commenced and is presented in a table format (Table 10.4) building on the two columns already developed.

The entries made in this table are simplified, incomplete and need to be further developed by pool management according to the specific attributes and administration of each public swimming pool or spa pool premises.

10.2.4 Implementation

A fourth column recording date of implementation (Date implemented) may be added to audit progress in the implementation of risk management strategies. Therefore the column headings become:

Table 10.5: Date implemented column of the risk management framework

Identified risk	Risk assessment	Management strategies	Date implemented

10.3 Dynamics of risk analysis

The risk analysis procedure is both externally and internally dynamic. The procedure is externally dynamic because risks and their characteristics will change over time and according to external forces and characteristics. A structured periodic review should be an essential component of the risk analysis.

The risk analysis procedure is also internally dynamic as the risk management strategies on one section may affect the strategies in another section. For example, the strategies in 1.1 iii) Bather load may be in conflict or enhance 2 iii) Disinfection.

Some tips for maintaining current health risk analysis procedures:

- When the first risk analysis framework is complete and independently confirmed, it should be signed by all pool management staff and accepted by the controlling organisation.
- The risk analysis should be reviewed annually.
- The risk analysis should be reviewed before corporate business planning and budgeting as the risk analysis may require planning and funding for particular risk management strategies.

Table 10.4: Management plan framework

Identified risk	Risk assessment	Management strategies
1. Contamination source		
1.1 Patrons		
i) General bather faecal pathogen load. Faecal pathogen load carried by bathers is always present	Likelihood – Medium Impact – Medium Priority = Medium	■ Develop techniques to decrease pathogen load into the premises ■ Encourage all bathers to enter the pool though the change room and ablutions facilities ■ Ensure ablutions facilities are private, convenient, comfortable and equipped with warm water and soap to encourage showering
ii) Bather pathogen load from skin infections. Infected skin may transmit micro-organisms to the pool, furnishings and directly to other bathers	Likelihood – Low Impact – Medium Priority = Low	■ Ensure all patrons pass through turnstiles and sufficient staff are available so that patrons can be scanned for obvious skin infections and lesions ■ Patrons with skin infections should be requested to refrain from swimming and to cover infections ■ Provide equipment which may be used to cover skin infections
iii) Bather load. Bather load may overwhelm circulation and disinfection capabilities	Likelihood – High in summer Impact – High Priority = High	■ Determine maximum instantaneous bather load as a function of pool depth and circulation rate ■ Develop protocols to ensure that bather load is not exceeded ■ Investigate ability to reduce turnover time during high bather loads
iv) Bather behaviour. Some behaviour such as spitting, spouting and nose blowing increases the pathogen load in the pool	Likelihood – High Impact – Medium	■ Discourage spitting, spouting and nose blowing or at least request patrons to use the scum gutter
v) Incontinent babies. Faecally incontinent babies are most likely to transmit disease	Likelihood – Impact – Priority =	■ Provide sufficient, conveniently located and well equipped baby change rooms ■ Prohibit the use of nappies and encourage the use of alternative catch all bathers ■ Prohibit pool side nappy changing ■ Provide suitable signage
vi) Crowd control. Unaware patrons may breach policy and procedures	Likelihood – Impact – Priority =	■ Employ sufficient staff to encourage compliance
vii) Bather ignorance. May lead to unhygienic practices	Likelihood – Impact – Priority =	■ Develop educational strategies ■ Use signs to encourage the most important hygienic practices e.g. Patrons are requested to shower before entering the pool
1.2 External contamination		
i) Windblown debris	L I P	■
ii) Bird contamination	L I P	■
iii) Litter	L I P	■
iv) Chemical control	L I P	■
2. Transmission pathway		■
i) Filtration	L I P	■
ii) Circulation	L I P	■
iii) Disinfection	L I P	■
iv) Raw water	L I P	■
v) Water temperature	L I P	■
vi) Emerging chlorine resistant diseases	L I P	■
vii) New disinfection techniques	L I P	■
viii) Faecal incidents	L I P	■
ix) Other incidents – blood spill	L I P	■
x) Pool surrounds – apron, grassed areas	L I P	■
xi) Stale water	L I P	■
3. Susceptible host		
i) Age profile	L I P	■
ii) Shock loads	L I P	■
iii) Immune deficiencies	L I P	■
iv) Behaviour	L I P	■
v) Comfort vs disinfection (mucous membrane attack)	L I P	■
vi) Personal equipment storage (towels)	L I P	■

10.4 Other plans

There are other plans, schedules and monitoring which could be incorporated into the health risk management framework. The other plans may include:

- Sanitation and cleaning schedules
- Maintenance schedules
- Pool sampling and monitoring
- Work Health and Safety plans.

10.5 Descriptive risk assessment and management of pools and spas

Appendix E provides an example of a descriptive risk assessment and management of pools and spas.

CHAPTER 11

Legislation

11.1 Overview

Public swimming pools and spa pools are controlled and regulated by the *Public Health Act 2010 and the Public Health Regulation 2012.* The legislation may be downloaded from the NSW Health website at: http://www.health.nsw.gov.au/environment/publicpools/Pages/default.aspx

This chapter provides an overview of the legislation.

11.2 The *Public Health Act 2010* (the Act)

The Act commenced on 1 September 2012. Some provisions do not commence until 1 March 2013. Control of public swimming pools and spa pools is contained in Part 3, Division 3, and sections 34 to 37.

Under the Act, a public swimming pool or spa pool is defined as means a swimming pool or spa pool to which the public is admitted, whether free of charge, on payment of a fee or otherwise, including:

(a) a pool to which the public is admitted as an entitlement of membership of a club, or
(b) a pool provided at a workplace for the use of employees, or
(c) a pool provided at a hotel, motel or guest house or at holiday units, or similar facility, for the use of guests, or
(d) a pool provided at a school or hospital,

but not including a pool situated at private residential premises.

The Act defines spa pool as including any structure (other than a swimming pool) that:

(a) holds more than 680 litres of water, and
(b) is used or intended to be used for human bathing, and
(c) has facilities for injecting jets of water or air into the water.

Under the Act, a swimming pool includes any structure that is used or intended to be used for human bathing, swimming or diving, and includes a water slide or other recreational aquatic structure.

Section 35 of the Act, which commences on 1 March 2013, requires occupiers of public swimming pools and spa pools to notify their local council of the existence of the pool and comply with the prescribed operating requirements, which are set out in schedule 1 of the Public Health Regulation (note that the prescribed operating requirements do not apply to natural swimming pools.

Section 36 of the Act requires the occupier of the public pool premises to disinfect the pool properly and keep the pool surrounds and amenities in a clean and hygienic condition. Compliance with Schedule 1 of the Regulation is a defence to prosecution under this section.

Section 37 requires the conspicuous display of any prohibition order which may be served on the occupier of the premises.

11.3 The *Public Health Regulation 2012*

Section 35 of the Public Health Act requires occupiers of public swimming pools and spa pools to comply with the prescribed operating requirements, which are set out in schedule 1 of the Public Health Regulation. Occupiers of natural swimming pools are exempt from this requirement. It is an offence not to comply with a prescribed operating requirement with a maximum penalty of 100 penalty units for an individual or 500 penalty units for a corporation for failure to comply.

The prescribed operating requirements sets out in schedule 1 of the Regulation is similar to the

Schedule 1 former NSW Health "Guidelines for the Disinfection of Swimming Pools and Spa Pools" known as the blue book.

If an occupier fails to comply with the prescribed operating requirements, an authorised officer can issue an improvement notice directing compliance with the prescribed operating requirement. If a prescribed operating requirement has not complied with a prescribed operating requirement, a prohibition order may also be issued if it is necessary to prevent or mitigate a serious risk to public health.

In addition, and the Regulation allows the Director-General (or delegate), by order in writing, to direct the occupier of the pool premises to close the pool if satisfied on reasonable grounds that the pool is a risk to public health. The order must state the reasons for closure and the occupier must comply with the order while it is in force and display the order at any entrance to the pool. The order can only be revoked in writing if the pool is no longer a risk to public health. The Director-General also has powers to direct an occupier of the pool to disinfect the pool or take other action if it is considered that the pool is a risk to public health.

Occupiers should be aware that from 1 March 2013 they will be required to notify the local council of the existence of the pool in the approved form and pay the prescribed fee.

From 1 March 2013, local councils will be required to maintain a register of the details of swimming pools and spa pools notified in its area.

11.4 Schedule 1 of the Regulation

Schedule 1 contains the necessary chemical parameters which must be followed to prevent risk to public health in a public pool. Additionally Schedule 1 specifies the frequency of testing and the keeping of records of testing. The contents of Schedule 1 are evidence based and the chemical parameters are based on the contents of this advisory document which have in turn been derived over many years. The chemical parameters conform with international requirements and recommendations of the World Health Organisation (WHO – Geneva), Centres for Disease Control (CDC – Atlanta, Georgia, USA), and the Pool Water Treatment Advisory Group (PWTAG – England).

Compliance with the requirements set out in schedule 1 is also a defence for prosecution under section 36 of the Act.

11.5 Enforcement of the Act and Regulation

Under the *Public Health Act 2010* and *Public Health Regulation 2012* there is a larger range of enforcement options. Of course the preferred option is the health education approach where swimming pool operators act in cooperation with Authorised Officers and consultants to produce pool water with absence of health risk.

However, where this does not occur there are a number of enforcement measures which range through:

- Warning letters
- On-the spot-fines (PINS)
- Improvement Notices
- Prohibition Orders, and
- Prosecution

The *Public Health Act 2010* and *Public Health Regulation 2012* should be consulted directly to determine these measures, the penalties and right of appeal.

Breakpoint chlorination (see section 4.4.1)

1. Combined chlorine and chloramines

Chloramines are probably the largest component of combined chlorine. Combined chlorine lowers disinfection rates, causes severe eye stinging and strong odours. Breakpoint chlorination is one technique to control combined chlorine, particularly inorganic chloramines.

Combined chlorine, commonly known as chloramines, forms when the hypochlorous acid component of free chlorine reacts with certain ammonia and organic nitrogen compounds. Ammonia and organic nitrogen compounds are introduced into a swimming pool or spa by components such as perspiration, urine, dust, dirt, leaves, cosmetics and incoming water supply. Perspiration and urine contain urea, some of which decomposes to form ammonia (NH_3). The amount of urine being excreted into a pool should be reduced as much as possible, as it is the most significant source of ammonia. High nitrogen levels, particularly in outdoor pools, are a precursor to unsightly and slippery algal growth and can support the growth of other micro-organisms.

The basic chemistry of chlorine and chloramines is outlined in section 4.4.1. In summary, ammonia (NH_3) can bond to a varying number of chlorines: monochloramine has one chlorine atom; dichloramine has two chlorine atoms; and trichloramine has three chlorine atoms. Each chloramine behaves slightly differently.

If the ratio of the weight of chlorine to ammonia is less than 5:1 and the pH is greater than 7.5

($HOCl + NH_3 \rightarrow H_2O + NH_2Cl$)

monochloramine is formed. Monochloramine is stable, unaffected by sunlight, not particularly odorous and is not very volatile. It has a low disinfection capacity.

If the ratio of the weight of chlorine to ammonia is greater than 10:1 and pH decreases below 7.5

($HOCl + NH_2Cl \rightarrow H_2O + NHCl_2$)

dichloramine is formed. Dichloramine is less stable, is more volatile being released on aeration by bathers, is almost unaffected by sunlight, and is odorous and offensive.

If the ratio of the weight of chlorine to ammonia is greater than 15:1 and pH is less than 7.4

($HOCl + NHCl_2 \rightarrow H_2O + NCl_3$)

trichloramine is formed. Trichloramine is unstable, breaks down in sunlight, has a nauseous and offensive odour and is very volatile being readily given off on aeration. It is particularly associated with severe eye stinging. Trichloramine is less a problem in outdoor pools but can be a major problem in poorly ventilated, indoor pools where it is released by bather agitation of the pool.

However, in an excess of free chlorine and a pH of 7.5 or higher and if the ratio of the weight of chlorine to ammonia is between 10:1 to 12:1, dichloramine is more likely to decompose to nitrogen gas (N_2) or nitrous oxide gas (NO) or nitrate (NO_3) and not produce trichloramine. These reactions can be competing depending on the pH and the excess of free chlorine available. An ideal pH based on chloramine destruction chemistry is 7.5.

When water supplies are chlorinated, ammonia is often added to form monochloramine to prolong disinfection throughout the reticulated water mains and reduce the growth of biofilms. This often increases the difficulty for pool operators who have to reduce the monochloramine in the water supply in the first instance before reaching breakpoint chlorination. Ideally, there should not be chloramines in a swimming pool, although some organic chloramines are unavoidable.

In best practice, an automatically controlled pool should never exceed 0.2 mg/L combined chlorine and the criteria limit of 0.5 mg/L chloramines should be set. Operators of older pools with non-compliant turnover rates will struggle to achieve a limit of 0.5 mg/L combined chlorine and should set an absolute upper limit of 1.0 mg/L combined chlorine. It may be necessary to install equipment such as ultraviolet (UV) light treatment to control combined chlorine in poorly performing indoor pools. A swimming pool consultant should be engaged for professional advice.

A constant and strong chlorine odour indicates a poorly operated pool. The smell is a result of di or trichloramine. If it is trichloramine, then patrons will also experience severe eye stinging.

Combined chlorine can be reduced in the following ways:

- A large proportion of combined chlorine comes from urine. Urine in a pool can be minimised by requiring people to walk through a change room and toilet area before entering the main concourse and by adequate signage directing people to go to the toilet before going to the pool area.
- Continuous or shock breakpoint chlorination is another technique to reduce chloramines.
- Chloramines can be reduced by continuously dumping pool water and diluting with fresh water that is lower in chloramines. However, water dumping is hard to justify in terms of water conservation practice. Where mains water is dosed with monochloramine to prolong disinfection in the water supply distribution system it will not dilute pool chloramines. Collecting and storing rainwater for dilution of total dissolved solids is becoming more popular.
- Ozone and UV light treatment is being increasingly used to reduce chloramines, particularly organic chloramines that are difficult to oxidise. Such treatment may require capital investment.
- Filtration enhancers are not necessarily helpful in removing chloramines, but they are helpful in reducing organic matter that could release nutrients and inorganic nitrogen into the pool water.
- Oxidisers, such as hydrogen peroxide and potassium monopersulphate, are helpful in oxidising or burning up organic material and removing chloramines. Firstly, oxidisers reduce the demand on free chlorine to oxidise pollutants. Secondly, oxidisers allow free chlorine to act more rapidly at a lower pH level and at a higher concentration. An occasional preventive shock dose of an oxidiser helps to lower chloramines and restore clarity and sparkle to the pool. The use of some oxidisers, particularly sodium monopersulphate, will lead to falsely elevated total and combined chlorine measurements.

2. Continual breakpoint chlorination theory

The following graph demonstrates the theory of breakpoint chlorination. On the left vertical axis is the chlorine concentration in mg/L which is zero at the bottom of the axis and increases with height. On the right vertical axis is the ammonia-nitrogen (i.e. ammonia measured as nitrogen) concentration also in mg/L which is zero at the bottom of the axis and increases with height. The bottom horizontal axis represents the ratio of chlorine (Cl_2) to ammonia (NH_3) by weight which is zero on the left and increases to the right. The bottom horizontal axis also represents time and increases from left to right. There are three inter-related lines on the graph:

- N CONC: (sigma ammonia-nitrogen concentration) represents the concentration of the sum of all forms of ammonia-nitrogen in the pool.
- Total Chlorine Applied: the constant dose of chlorine being introduced into the pool.
- Measured Chlorine Residual: the measured total chlorine residual in the pool.

The breakpoint curve is a graphical representation of chemical relationship that exists with constant addition of chlorine to swimming pool water containing a small amount of ammonia-nitrogen. This graph represents a swimming pool where bathing has ceased and no further ammonia-nitrogen is introduced into the pool. During an overnight period sodium hypochlorite is added at a constant rate. This curve has three zones.

Zone 1: Staring from the left side of the graph; there is already a concentration of ammonia-nitrogen (N CONC) in the pool from bathers. Chlorine has been allowed to fall to zero and Total Applied Chlorine and Measured Chlorine Residual are both zero. Chlorine is then added at a constant rate. The principal reaction in Zone 1 is the reaction between chlorine and the ammonium ion. This reaction results in a Measured Total Chlorine of only monochloramine to the hump in the curve. The hump occurs, theoretically, at chlorine to ammonia-nitrogen weight ratio of 5:1. This ratio indicates the point where the reacting chlorine and ammonia-nitrogen molecules are present in solution in equal numbers. Monochloramine does not readily degrade.

Zone 2: The breakpoint phenomenon occurs in this zone which is also known as the chloramine destruction zone.

As the weight ratio exceeds 5:1, some of the monochloramine starts reacting with further addition of chlorine to form dichloramine, which is about twice as germicidal as monochloramine. A pure dichloramine residual has a noticeable disagreeable taste and odour, while monochloramine does not. Total Chlorine Applied is still increasing and both the Concentration of ammonia-nitrogen and Measured Chlorine Residual decrease rapidly. This rapid decrease occurs because the dichloramine is reacting immediately with additional hypochlorous acid in a series of destruction reactions to form volatile compounds and other by-products such as nitrogen gas, nitrate and chloride. Therefore, ammonia and chlorine are consumed in the reactions and lost from the pool. Thus, additional chlorine is required to destroy ammonia and chloramines.

The breakpoint (Point A) is the point of the lowest concentration of Measured Chlorine Residual where nuisance chlorine residuals remain and where ammonia-nitrogen is not detected. The nuisance chlorine residuals are mainly organic chloramines which cannot be oxidised any further by reacting with hypochlorous acid.

Zone 3 is to the right of the breakpoint (Point A) and is where a free chlorine residual will appear. The total residual consists of the nuisance residuals plus free chlorine. If trichloramine is formed, it will appear in this zone. In practice it has been found the most pleasant water for bathing will occur if more than 85% of the total chlorine is free chlorine.

In reality, ammonia-nitrogen does not stay static but is continually added while the pool is open to the public. **To achieve breakpoint chlorination, chlorination must continue after the pool has been closed to the public to ensure oxidation of the additional chloramines every night.**

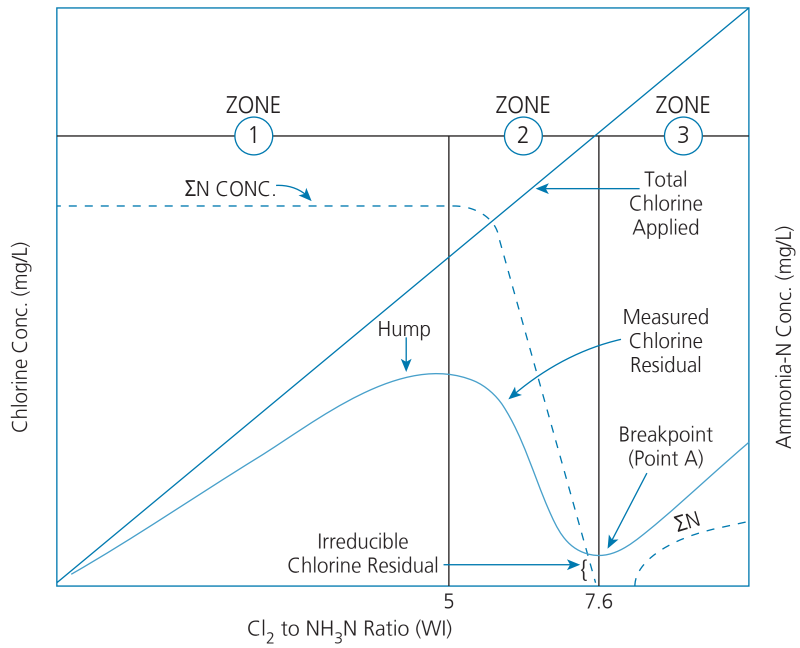
The shape of the breakpoint curve is affected by contact time, temperature, concentration of chlorine and ammonia, and pH. Higher concentrations of the chemicals increase the speed of the reactions.

3. Shock breakpoint chlorination

Shock breakpoint chlorination involves oxidising combined chlorine with a slug or shock dose of chlorine to generate sufficient free chlorine which is at least ten times the concentration of the combined chlorine.

It is preferable to operate the pool at a pH between 7.5 and 7.6 to reduce the likelihood of trichloramine formation.

- Adding any less chlorine than calculated will not achieve breakpoint.
- Adding insufficient chlorine will not eliminate combined chlorine and could worsen the situation.
- In indoor pools it is critical to have good ventilation when reaching breakpoint. Some chloramines can evaporate and then re-dissolve in the water and if a pool blanket is used none of the volatile reaction by-products can evaporate.



Example of shock breakpoint chlorination

At the start of the weekend, the Saturday morning testing of a 200 000-litre indoor swimming pool revealed total chlorine of 2.3 mg/L and a free chlorine concentration of 1.8 mg/L giving a barely acceptable combined chlorine reading of 0.5 mg/L.

After a heavy weekend of bathing, testing on Sunday night revealed total chlorine of 2.3 mg/L and free chlorine of 0.5 mg/L giving an unacceptable combined chlorine concentration of 1.8 mg/L. The pH was 7.4. In order to prepare for a swimming school class on Monday, it was decided to shock breakpoint chlorinate overnight to reduce the chloramines to an acceptable level.

The general rule is to shock dose free chlorine to 10 times the chloramine concentration. In this case, 10 times the chloramine concentration equates to 18.0 mg/L of free chlorine. In order to do this, the pool was closed to bathers. A calculation was made to add 36 L of sodium hypochlorite (liquid chlorine) by broadcasting using a plastic (not metal as metal may react adversely with the chlorine) watering bucket around the edges of the pool. The pool circulation system (but not the dosing system) was run all night. Because, at a pH of 7.4, trichloramine may be formed, an aerator was inserted into the pool to release the volatile chloramines and the windows and doors were all opened to maximum. By the next morning, the chloramines were 0.2 mg/L although the free chlorine was elevated to 5.0 mg/L giving oxidation capacity for the swimming class due that morning.

The ideal way to minimise the formation of trichloramine is to ensure that free chlorine is more than 85% of total chlorine at all times. In addition, some oxidiser such as hydrogen peroxide can be added that leaves no residual and boosts the performance of free chlorine without over adding chlorine.

The benefits of shock breakpoint chlorination are that it:

- Allows disinfection to rapidly catch up
- Eliminates chloramines
- Controls *Cryptosporidium* more effectively
- Controls biofilms
- Provides extra oxidation
- Aids filtration
- Aids clarification.

Performing shock breakpoint too frequently and at too high of a free chlorine concentration could affect pool materials and finishes and it is preferable to operate using continuous breakpoint chlorination.

Sample log sheet

(See Chapter 5, section 5.10.) This sheet should be modified to suit the type of pool.

Appendix B - Sample Log Sheet
(see Chapter 5, section 5.10) This sheet should be modified to suit the type of pool

<Insert Name of Centre> <Insert Name of Pool> Date ____________

Pool water testing

			<Insert POR range for this pool>	< Insert POR range for this pool>	Break point 0.0 mg/L at the first test of the day	pH range 7.0-7.8	Total alkalinity range 80-200 mg/L	Calcium hardness mg/L	Incidents / Corrective actions taken	Name of tester	Signature of tester
Time testing due	Time testing conducted	Temp °C	ORP mV or Free chlorine mg/L DPD tablets No.1(F)	Total chlorine mg/L DPD tablets Nos.1+3 (T)	Combined chlorine mg/L Total-Free (T) - (F)	pH	Total alkalinity	Calcium hardness			
6 am											
9 am											
12pm											
3 pm											
6pm											
9pm											
Daily average											

Combined chlorine must not exceed 1.0 mg/L and should not be more than half of free chlorine

Cyanurate acid concentration (weekly measurement) ____________ Date ____________

Water Balance

Using the water balance chart on reverse, calculate the Langelier Saturation Index (LSI). The ideal LSI is 0.2 and the range is –0.5 to 0.5.

LSI = pH + TF + CF + AF - 12.1
where:
TF = Temperature factor
CF = Calcium Hardness factor
AF = Alkalinity Factor

____ (pH) + ____ (TF) + ____ (CF) + ____ (AF) - 12.1 = ____ (LSI)

Calculated by (initial) ______________________

Daily Maintenance Log

Detail what was undertaken and at what time of the day.

Maintenance area	Maintenance undertaken	Time of maintenance	Signature

Review by manager

Data and corrective action to be reviewed by facility manager daily

Further action required or taken or other comments	Name of Manager	Signature of manager	Date

Water balance chart

Temperature (C°)	Temperature Factor	Calcium (hardness)	Calcium hardness factor	Total alkalinity	Alkalinity factor
0	0.0	5	0.3	5	0.7
3	0.1	25	1.0	25	1.4
8	0.2	50	1.3	50	1.7
12	0.3	75	1.5	75	1.9
16	0.4	100	1.6	100	2.0
19	0.5	150	1.8	150	2.2
24	0.6	200	1.9	200	2.3
29	0.7	300	2.1	300	2.5
34	0.8	400	2.2	400	2.6
40	0.9	800	2.5	800	2.9
53	1.0	1000	2.6	1000	3.0

Notes for modifying this log sheet for your pool:

- This log sheet is available electronically from the Department's web site: www.health.nsw.gov.au
- Use a separate sheet for each pool for each day.
- Print on different coloured paper for each pool.
- *Change the Health Prescribed Operating Requirements (POR)* levels so they are appropriate for the type of pool. This depends on if the pool is indoor or outdoor, the temperature and the type of disinfection used. See the *Public Health Regulation 2012, Schedule 1*
- If used for a bromine disinfected pool the breakpoint is really important and DPD1 measures bromine.
- If used for an ozone pool, insert a space to record when a check is done and the results.
- If an automatic controller is used, and the results are input, then there needs to be a place to enter a manual reading to compare with the automatic reading.

APPENDIX C

Components to consider in recycling swimming pool backwash water

(See Chapter 6, section 6.5.2)

(Developed for use with Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1) 2006)[40]

Framework element	Activity
Element 1: Commitment to responsible use and management of recycled water quality **Components:** ■ Recycled water policy ■ Regulatory and formal requirements ■ Engaging stakeholder	**Regulatory framework – compliance** **Water Quality Guidelines:** ■ NSW Health. Public Swimming Pool and Spa Pool Guidelines[45] ■ Australian Drinking Water Guidelines[39] **Health Risk Assessment Guidelines:** ■ Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1), 2006[40] **Develop a recycled water policy**
Element 2: Assessment of the recycled water system **Components**: ■ Identify intended uses and source of recycled water ■ Recycled water system analysis	**Source of water** ■ Backwash from swimming pool(s) **Treatment** ■ Reverse osmosis ■ Ultrafine filtration (UFF) and/or granular activated carbon (GAC) may be recommended **Intended uses** ■ Recreational swimming ■ Hydrotherapy (possibly immunocompromised clients) ■ Learn to swim (infants not toilet trained) **Exposure routes** ■ Ingestion (100 mL) – more for infants ■ Dermal: disinfection by-product (DBP) – trihalomethanes (THM) ■ Inhalation: DBP – THM **Assessment of water quality data** ■ Turbidity, pH ■ Microbial quality ■ Chemical quality (DBP-THMs) ■ Water quality indicators: total dissolved solids (TDS) /conductivity
Component: ■ Hazard identification and risk assessment	**Treated backwash water to be tested prior to reuse** ■ Microbial hazards ■ Chemical hazards ■ Hazards from failures ■ Control to prevent failures
Element 3: *Preventive measures for recycled water management* **Components:** ■ Preventive measures and multiple barriers ■ Critical control points	**Preventive measures** ■ Control of bather hygiene, showers prior to pool entry ■ Treatment: best available technology (RO, UFF, GAC, ultraviolet [UV]) ■ Validation of treatment system ■ Pipework purple with reuse caution and signage (may be needed) ■ Documentation of responsibilities, operational procedures ■ Backflow and cross connection prevention ■ Controls – monitoring, shutdown upon failure **Communication** ■ Recycled water should be tested prior to reuse, otherwise alternative clean water source should be used ■ Failures should be communicated and reported ■ Education program for operational staff ■ Validation prior to commissioning to ensure that recycled water complies with the standards for drinking water ■ On-line monitoring of pool water for TDS, free chlorine and/or oxidation-reduction potential (ORP) ■ Determine critical control points
Element 4: *Operational procedures and process control*	**Documented procedures** ■ Operational monitoring (auditing of critical limits for TDS/conductivity) ■ A contingency plan should be developed to effectively deal with pool contamination events ■ Corrective active

Framework element	Activity
Element 5: *Verification of recycled water quality and environmental sustainability*	**Water quality monitoring (turbidity, TDS, DBP, microbial)** ■ Receiving water monitoring – swimming pool water ■ Documentation and reliability ■ Annual reporting of water quality monitoring results to Public Health Unit (PHU) ■ Short-term evaluation of results ■ Corrective action
Element 6: *Management of incidents and emergencies*	■ Potential public health problems should be reported to PHU ■ Non-compliance with approval conditions to be reported immediately to PHU ■ Incident and emergency response protocol
Element 7: *Operator, contractor and end user awareness and training*	■ Skilled and trained operator
Element 8: *Community involvement and awareness*	■ Community consultation and education
Element 9: *Validation, research and development*	■ Validation of processes ■ Design of equipment ■ Investigative studies and research monitoring
Element 10: *Documentation and reporting*	■ Management of documentation and records ■ Reporting
Element 11: *Evaluation and audit*	■ Long term evaluation of results ■ Audit of recycled water quality management
Element 12: *Review and continual improvement*	■ Review by senior management ■ Recycled water quality management improvement plan

* For irrigation reuse applications refer to the Department of Environment and Climate Change Environmental Guidelines *Use of Effluent by Irrigation*

Components to consider in water harvesting

(See Chapter 6, Section 6.6.) (Developed for use with *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1),* 2006) [40]

Framework element	Activity
Element 1: *Commitment to responsible use and management of rainwater to top-up swimming pools* **Components:** Rainwater use policy Regulatory and formal requirements Engaging stakeholders	Regulatory framework – compliance **Water Quality Guidelines:** ■ NSW Health. Public Swimming Pool and Spa Pool Guidelines[46] **Heath risk assessment guidelines:** ■ Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1), 2006[40] ■ EnHealth. Guidance on use of rainwater tanks. May 2004[42] ■ Develop a rainwater use policy
Element 2: *Assessment of the water system* **Components:** Identify intended uses	**Source of water** ■ Rainwater tank **Treatment** ■ First flush system ■ UFF filtration or other pre-treatment ■ Disinfection: ultraviolet (UV) ■ Introduced into the pool plant and not directly into the pool **Intended uses** ■ Recreational swimming **Exposure routes** ■ Ingestion (100 mL) – more for infants ■ Dermal: disinfection by-product (DBP) – trihalomethanes (THM) ■ Inhalation: DBP - THM **Assessment of water quality data** ■ Microbial quality ■ Chemical quality (heavy metals) pH, total dissolved solids (TDS), turbidity **Water Quality Indicators** ■ Turbidity (NTU), TDS ■ Oils and grease ■ Salts (coastal locations) ■ Heavy metals (lead, copper) ■ Microbiological indicators
Component: Hazard identification and risk assessment	**Rainwater to be validated prior to use** ■ Microbial hazards ■ Chemical hazards ■ Hazards from failures
Element 3: *Preventive measures for recycled water management* **Components:** Preventive measures and multiple barriers Critical control points	■ Prevention – roofing materials, flashing (not lead) ■ Treatment – best available technology (first flush system) ■ Validation of treatment system ■ Documentation of responsibilities, operational procedures ■ Controls – monitoring, shutdown **Multiple barriers/prevention/communication** ■ Rainwater water should be tested prior to use. ■ Failures should be communicated and reported to the Public Health Unit (PHU) ■ A contingency plan should be developed to effectively deal with rainwater contamination events. ■ Education program for operational staff ■ Validation prior to commissioning to ensure that rainwater complies with the Australian Drinking Water Guidelines in relation to e.g. turbidity, TDS, oils and grease, heavy metals, and microbial indicators. ■ On-line monitoring of pool water for TDS, turbidity, free chlorine and oxidation-reduction potential (ORP) (may be required) ■ Determine critical control points
Element 4: *Operational procedures and process control*	**Documented procedures** ■ Operational monitoring ■ Develop a contingency plan for contamination events ■ Corrective advice

Framework element	Activity
Element 5: *Verification of rainwater quality*	■ Water quality monitoring ■ Receiving water monitoring ■ Documentation and reliability ■ User satisfaction ■ Short-term evaluation of results ■ Corrective action
Element 6: *Management of incidents and emergencies*	■ Communication ■ Incident and emergency response protocol
Element 7: *Equipment capability and maintenance*	■ Operator, contractor and end user awareness and training
Element 8: *Community involvement and awareness*	■ Community consultation and education
Element 9: *Validation, research and development*	■ Validation of processes ■ Design of equipment ■ Investigative studies and research monitoring
Element 10: *Documentation and reporting*	■ Management of documentation and records ■ Reporting
Element 11: *Evaluation and audit*	■ Long term evaluation of results ■ Audit of rainwater - water quality management
Element 12: *Review and continual improvement*	■ Review by senior management ■ Continual improvement

APPENDIX E

Descriptive risk assessment and management of pools and spas

(See section 10.5)

Hazards **Illnesses that may be transmitted in swimming pools and spa pools from pathogenic micro-organisms e.g. bacteria, viruses, and protozoa**	
Risk factors/issues	**Risk management**
Inadequate disinfection High risk: non-automated chlorination, high pH, high turbidity, high organic load, high combined chlorine, high cyanuric acid	*Education* Ongoing education of pool operators Pool policy to recommend showering *Regulation* Disinfection safeguards (compliance checks/closure of pools when they present a serious public health risk) Frequently testing of pools and verification by analysis of Heterotrophic Plate Count, Thermotolerant coliforms (or *Escherichia coli)* and *Pseudomonas aeruginosa* Training and certification of pool operators (nationally standardised)
Infectious accident High risk: toddlers pools, hydrotherapy pools and where loose faecal accidents occur	*Education* To inform the community about the risks of faecal accidents and the ways to avoid contaminating a pool People with a diarrhoeal illness or for a two week period following a diarrhoea illness should not use a swimming pool or a spa pool Bowel incontinent adults should avoid using a swimming pool or spa pool Babies and children that are not toilet trained should wear waterproof pants Recommend showering with soap prior to bathing Parents should encourage children to use a toilet regularly *Regulation* Decontamination safeguards to reduce risks by ensuring a prompt response to a potentially infectious incident. Pool closures may be warranted where a pool presents a serious public health risk Spa pools and other small pools should be emptied and cleaned following an infectious accident Separate filtration system for toddlers' pools and hydrotherapy pools. Pool supervisors need to be trained and certified to ensure that they know how to deal with a faecal accident
High bather load/bather shedding High risk: spa pools. (High bather load correlates with low levels of free chlorine)	*Education* To inform the community about the risks associated with high bather loads / bather shedding *Regulation* Restrict bather numbers, especially in spa pools Ensure adequate filtration and backwashing to remove pollutants Frequent draining and cleaning of spa pools (dependent on water restrictions) Ensure adequate disinfection and that cyanuric acid is not too high
Pollution from bathers and the environment Bathers: lotions, dirt, bubble bath, sweat, skin and hair Environment: vegetation, insects, birds, animal hair, dust	*Education* Recommend showering before entering a pool Inform the community about the risk of pollution from bathers and the environment *Regulation* Prevent the entry of polluted material into a pool Ensure the provision of easy access toilets and showers (with soap) Adequate filtration and disinfection Dilution of pool water with fresh water
Microbiological failure High risk: stagnant, turbid pools Poor disinfection Poor pool filtration	*Education* Pool operators *Regulation* Ensure that new pools are designed appropriately Ensure disinfection levels are adequate Ensure efficient pool turnover and filtration Recommend that pool operators are trained in pool maintenance Closure of pool until problem is rectified
Ingestion of water High risk: head emersion, wave pools, water slides	*Education* Educate parents and young children that pool water may contain pathogens and that it should not be swallowed
Length of exposure High risk: spas with *P. aeruginosa*; heat stress	*Education* Risk associated with length of exposure *Regulation* To ensure that the presence of *P. aeruginosa* is regularly monitored To prevent high temperatures.

Hazards Illnesses that may be transmitted in swimming pools and spa pools from pathogenic micro-organisms e.g. bacteria, viruses, and protozoa	
Risk factors/issues	**Risk management**
Open wound or infection High risk: infectious material (e.g. blood, pus)	*Education* To inform the community about the risk to others and self from entering a pool with an open wound. *Regulation* To prevent people with open wounds or infections from entering a public pool
Turbidity High risk: poor pool filtration	*Education* To ensure that pool operators properly maintain their pool(s) *Regulation* Compliance checks and appropriate upgrading of pool filtration equipment if required
Outbreaks of infectious diseases Poorly maintained pools Faecal accidents Use of pools by infectious people	*Education* Inform the community about the outbreak, symptoms of the illness, treatment, and if necessary precautions to prevent further spread *Regulation* Close the pool and require appropriate safeguards to prevent further infection e.g. shock dosing / flocculation and coagulation
Pool malfunction	*Regulation* On pool commissioning or pool upgrade appropriate microbiological and dye testing should be undertaken to confirm microbiological safe conditions and adequate pool circulation (and absence of dead spots)
Poor compliance of disinfection and microbiological criteria	*Education* Publication/distribution of compliance studies/results *Regulation* Development of an Environmental Health Management System to better monitor and control compliance problems

Glossary / Abbreviations

Term	Definition
Acidic	Solution with a pH between 0 and 7 (see pH)
Alkaline (basic)	Solution with a pH between 7 and 14 (see pH)
Alkalinity	Alkalinity is the acid neutralising capacity of water
Amperometric	Measurement of a chemical concentration using an electrical current (amperes)
APHA	American Public Health Association
APVMA	Australian Pesticides and Veterinary Medicines Authority
AS/NZS	Australian Standard / New Zealand Standard
Active chlorine	Free chlorine that is within the acceptable pH range of 7.2-7.6
Backwash	The process of cleaning a pool filter by reversing water flow
Bather load	The number of bathers per pool area
BCDMH	Bromo-chloro-dimethylhydantoin: the most common bromine-based swimming pool disinfectant
Biofilm	A complex of micro-organisms held in a slime layer of polysaccharides often covering the inner surface of pipes
Breakpoint chlorination	The process of maintaining sufficient free available chlorine in the pool water to chemically convert chloramines and ammonia-nitrogen compounds to inert nitrogen gas. Theoretically where total chlorine equals free available chlorine and combined chlorine is zero
CFU	Colony forming units: a unit expressing the number of counted bacterial colonies grown on a plate
Chloramines	Compounds formed from reaction of chlorine with amine groups (ammonia)
Chlorine	Chlorine gas is Cl_2 which when dissolved in water forms hypochlorous acid and the hypochlorite ion
Chlorination	The application of chlorine to water for disinfection
Clarity	Clearness or lack of cloudiness in water; indicated by the distance through the water at which an object can be seen
Coagulation	The process of particles clumping together to form a mass with the aid of a flocculent material
Coliforms	A group of bacteria normally present in the colon of warm blooded animals
Colorimetric	A chemical determination method involving a colour change in the substrate detectable by the eye
Combined chlorine	Chlorine that has combined with ammonia, ammonium compounds or organic matter. Chloramines are a major component of combined chlorine
Cryptosporidiosis	A gastrointestinal illness caused by the protozoan parasite *Cryptosporidium parvum*
Ct	A measure of the concentration (C) of disinfectant multiplied by its contact time (t) to produce a measured inactivation rate of a particular micro-organism
Disinfectant	Also called sanitiser or biocide. A compound or substance used for disinfection
Disinfection	Also called sanitising. A process intended to inactivate, kill or remove the vegetative cells of pathogenic (disease causing) micro-organisms, by direct exposure to chemical or physical agents. Disinfection does not necessarily inactivate spores and other resistant structures such as oocysts
DBP	Disinfection by-product
DPD method	The N,N-diethyl-p-phyenylene diamine method of measuring free available chlorine and total chlorine concentrations or equivalent bromine concentrations in swimming pool or spa pool water
Epidemiology	The study of the distribution and determinants of health-related states or events in specified populations, and the application of the study to the control of health problems
Faecal-oral route of transmission	Spread of a communicable (infectious) disease through the ingestion of faecally-contaminated material
Filter	A device or material for removing suspended particles from swimming pool or spa pool water fitted to the circulation system
Free bromine	Also known as free available bromine. The sum of hypobromus acid and hypobromite ion. When measured using the DPD tablet No. 1 method monobromamine is included in the measurement
Free chlorine	Also known as free available chlorine"or free residual chlorine. The sum of the concentrations of hypochlorous acid and hypochlorite ion. Measured by using DPD tablet No. 1

Term	Definition
FC	Faecal coliforms are facultatively-anaerobic, rod-shaped, gram negative, non-sporulating, bacteria. They are capable of growth in the presence of bile salts or similar surface agents, oxidase negative, and produce acid and gas from lactose within 48 hours at 44 ± 0.5°C. The faecal coliform assay should only be used to assess the presence of faecal matter in situations where faecal coliforms of non-faecal origin are not commonly encountered
FS	Faecal streptococci present in human and animal intestines, but also in the stomach. Many species of strepotcoccus are pathogenic. They cause diseases such as bacterial pneumonia, ear infection and bacterial meningitis.
h	Hour
Halogen	Chemicals in the halogen group of the periodic table, including fluorine, chlorine, bromine and iodine
Hazard	The capacity of an agent to produce a particular type of adverse health or environmental effect; or a set of circumstances that could lead to harm
Hazard identification	The identification, from animal and human studies, in vitro studies and structure-activity relationships, of adverse health effects associated with exposure to an agent
Host	A person or other living animal or plant that harbours or nourishes another organism (parasite)
HPC	The heterotrophic plate count, formerly known as the standard plate count, is a procedure for estimating the number of live heterotrophic (an organism that cannot synthesise its own food and is dependent on complex organic substances for nutrition) bacteria in water
Health risk assessment	The process of estimating the potential impact of a chemical, biological, physical or social agent on a specified human population system under a specific set of conditions and for a certain timeframe
Health risk management	The process of evaluating alternative actions, selecting options and implementing them in response to health risk assessments. The decision making will incorporate scientific, technological, social, economic and political information. The process requires value judgements, e.g. on the tolerability and reasonableness of costs
Indicator	Any parameter used to produce a specific measure of the quality of water
Make-up-water	Water used to replace lost swimming pool or spa pool water
mg	milligram; one thousandth of a gram (10^{-3}g)
mg/L	milligram per litre (roughly equivalent to ppm: parts per million)
micron	Micrometre: one millionth of a meter (10^{-6}m) (μm)
micro-organism	Any organism too small to be seen by the naked eye
mL	millilitre; one thousandth of a litre (10^{-3}L)
Oocyst	Encapsulated eggs that are the infective form of a parasite
Operator / occupier	That person who has control and management of the swimming pool and/or spa pool.
ORP	Oxidation-reduction potential; also known as Redox
Outbreak	Two or more cases of a communicable (infectious) disease related in the same place and time and with a common exposure; cluster has a similar meaning but usually refers to smaller numbers
Pa	*Pseudomonas aeruginosa*: a Gram-negative, aerobic, rod-shaped bacterium. It is an opportunistic human pathogen (does not normally cause disease at a particular site but may cause a disease as a result of a compromised immune system)
Parasite	An organism that uses the body of another organism to support its growth and reproduction
Pathogen	An organism capable of causing disease symptoms in another organism
pH	A scale (ranging from 0 to 14) which measures the inverse logarithmic concentration of the H^+ ion in water that indicates the acid or alkali condition of the water. pH 7 is neutral
Photometric	A chemical determination method involving a colour change intensity in the substrate detectable a beam of light set at a particular wavelength
Pool turnover	see turnover rate
Pool inlet	The point where treated water is returned to the pool
Pool outlet	The point where pool water flows from the pool to the circulation and treatment systems
PWTAG	Pool Water Treatment Advisory Group (England)
Recycle	Recycle means to use some material or matter again after suitable treatment
Reuse	Reuse is to use some material or matter again without treatment
Risk	The probability that, in a certain time frame, an adverse outcome will occur in a person etc that is exposed to a particular dose or concentration of a hazardous agent, i.e. it depends on both the level of toxicity of the agent and the level of exposure
Shock dose	The addition of pool chemicals to pool or spa water to achieve concentrations of at least 10 mg/L of chlorine for the destruction of combined chlorine, micro-organisms, and other impurities
Skimmer gutter	A drainage system provided to collect surface water flow from the swimming pool or spa pool and return it to the treatment plant or to waste

Term	Definition
Skimmer weir	A device provided to ensure that swimming pool or spa pool water is drawn from the surface for return to the treatment plant or to waste
Spa pool	A pool or other water-retaining structure designed for human use (but not for swimming): (a) that is capable of holding more than 680 L water; and (b) that incorporates, or is connected to, equipment that is capable of heating water contained in it to above 26ºC and injecting air bubbles or water into it under pressure so as to cause general turbulence in the water
Superchlorination	The addition of sufficient chlorine to a swimming pool or spa pool to raise the level of free available chlorine to greater than ten times the combined chlorine concentration (usually about 8-10 mg/L) for the destruction of chloramines
Total alkalinity	Sometimes called reserve alkalinity. A measure of the total amount of alkaline compounds in a water body, usually expressed as mg/L calcium carbonate ($CaCO_3$)
Total chlorine	The sum of combined chlorine and free available chlorine. Measured by adding DPD tablet No. 3 after a DPD tablet No. 1 to a sample of pool water
Thermotolerant Coliforms	Bacteria that originate from the gut of warm blooded animals and are used as an indicator of faecal contamination. Similar to faecal coliforms
TDS	Total dissolved solids. A measure of the total amount of dissolved elements and compounds in water expressed as mg/L
TPC	Total plate count: see Heterotrophic Plate Count
Turbidity	The degree to which suspended particles in a pool water obscure visibility
Turnover rate	The period of time required to achieve complete exchange the equivalent of one complete volume of pool water through the filter
WHO	World Health Organization

References

1. Heyman DL, editor. Control of Communicable Diseases in Man. 18th Edition. Washington DC: American Public Health Association, 2004.

2. World Health Organization (WHO). Guidelines for Safe Recreational-Water Environments Volume 2: Swimming Pools and Similar Environments. World Health Organization, Geneva: 2006.

3. Hunter PR. Adenoviral infections. Waterborne disease: epidemiology and ecology. Chichester, John Wiley & Sons, 1997.

4. Tallis G, Gregory J. An outbreak of hepatitis A associated with a spa pool. Commun Dis Intell 1997;21(23):353-4.

5. Kappus KD, Marks JS, Holman RC, Bryant JK, Baker C, Gary GW,et al. An outbreak of Norwalk gastroenteritis associated with swimming in a pool and secondary person-to person transmission. Am J Epidemiol 1982;116(5):834-9.

6. Maunula L, Kalso S, von Bonsdorff CH, Ponka A. Wading pool water contaminated with both noroviruses and astroviruses as the source od a gastroenteritis outbreak. Epidemiol Infect 2004;132:737-43.

7. Rigo MV, Martinez-Campillo F, Verdu M, Cilleruelo S, Roda J. Risk factors linked to the transmission of papillomavirus in the school environment. Alicante, 1999. Aten Primaria 2003;31(7):415-20.

8. Choong KY, Roberts LJ. Molluscum contagiosum, swimming and bathing: a clinical analysis. Aust J Dermatol 1999;40(2):89-92.

9. Brewster DH, Brown MI, Robertson D, Houghton DL, Bimson J, Sharp JCM. An outbreak of *Escherichia coli* O157 associated with a children's paddling pool. Epidemiol Infect 1994;112:441-7.

10. Hildebrand JM, Maguire HC, Holliman RE, Kangesu E. An outbreak of *Escherichia coli* O157 infection linked to paddling pools. Commun Dis Rep CDR Rev 1996;6(2):R33-6.

11. Althanus H. Legionellas in swimming pools. AB Archiv Badewesens 1986;38:242-5 (In German).

12. Bornstein N, Marmet D, Surgot M, Nowicki M, Arslan A, Esteve J, et al. Exposure to *Legionellae* at a hot spring spa: a prospective clinical and serological study. Epidemiol Infect 1989;102:31-6.

13. Mashiba K, Harmamoto T, Torikai K. A case of Legionnaires' disease due to aspiration of hot spring water and isolation of *Legionella pneumophila* from hot spring water. Kansenshogaku Zasshi 1993;67:163-6 (In Japanese).

14. Calvert J, Storey A. Microorganisms in swimming pools – are you looking for the right one? J Instit Environ Health Officers 1988;(96)7:12.

15. Rivera JB, Adera T. Assessing water quality. *Staphylococci* as microbial indicators in swimming pools. J Environ Health 1991;53(6):29-32.

16. Crone PB, Tee GH. Staphylococci in swimming pool water. J Hyg (Lond) 1974;73:213-20.

17. Rocheleau S, Desjardins R, Lafrance P, Briere F. Control of bacteria populations in public pools. Sciences et Techniques de l'eau 1986;19:117-28.

18. Embil J, Warren P, Yakrus M, Corne S, Forrest D, Hershfield E. Pulmonry illness associated with exposure to *Mycobacterium-avium* complex in hot tub water. Chest 1997;111(3:)534-6.

19. Collins CH, Grange JM, Yates MD. *Mycobacterium* in water. J App Bacteriol 1984;57(2):193-211.

20. Hrudey SE, Hrudey JH. Safe Drinking Water: Lessons from recent outbreaks in affluent nations. London: IWA Publishing, 2004

21. Puech MC, McAnulty JM, Lesjak M, Shaw N, Heron L, Watson JM. A statewide outbreak of cryptosporidiosis in New South Wales associated with swimming pools. Epidemiol Infect 2001;126:389-96.

22. Harter L, Frost F, Grunenfelder G, Perkins-Jones K, Libby J. Giardiasis in an infant swim class. Am J Public Health 1984;74(2):155-6.

23. Greensmith CT, Stanwick RS, Elliott BE, Fast MV. Giardiasis associated with the use of a waterslide. Manitoba Health, Winnipeg, Canada. Pediatric Infect Dis J 1988;7(2):91-4.

24. Porter JD, Ragazzoni HP, Buchanon JD, Waskin HA, Juranek DD, Parkin WE. Giardia transmission in a swimming pool. Am J Public Health 1988;78(6):659-62.

25. Faechem RG, Bradley DJ, Garelick H, Mara DD. Sanitation and disease: Health aspects of excreta and wastewater management. New York, NY: John Wiley and Sons, 1983.

26. Ma P, Visvesvara GS, Martinez AJ, Theodore FH, Dagget PM, Sawyer TK. Naegleria and Acanthamoeba infections:review. Rev Infect Dis 1990;12:490-513.

27. Martinez AJ. Infections of the central nervous system due to Acanthamoeba. Rev Infect Dis 1991;13:S399-S402.

28. Kilvington S, White DG. Acanthamoeba: biology, ecology and human disease. Rev Med Microbiol 1994;5:12-20.

29. Kee F, McElroy G, Stewart D, Coyle P, Watson J. A community outbreak of echovirus infection associated with an outdoor swimming pool. J Public Health Med 1994;16:145-8.

30. Friedman MS, Roels T, Koehler JE, Feldman L, Bibb WF, Blake P. *Escherichia coli O157:H7* outbreak associated with an improperly chlorinated swimming pool. Clin Infect Dis 1999;29(2):298-303.

31. Harter L, Frost F, Grunenfelder G, Perkins-Jones K, Libby J. Giardiasis in an infant and toddler swim class. Am JPublic Health 1984;74(2):155-6.

32. Lenaway DD, Brockmann R, Dolan GJ, Cruz-Uribe F. An outbreak of an enterovirus illness at a community wading pool: implications for public health inspection programs. Am J Public Health 1989; 79(7):889-90

33. Butler T, Ferson MJ. Faecal pollution of ocean swimming pools and stormwater outlets in eastern Sydney. Aust NZ J Public Health. 1997;21(6):567-71.

34. Puech MC, McAnulty JM, Lesjak M, Shaw N, Heron L, Watson JM. A statewide outbreak of cryptosporidiosis in New South Wales associated with swimming at public pools. Epidemiol Infect 2001;126(3):389-96.

35. Rycroft RJ, Penny PT. Dermatoses associated with brominated swimming pools. Br Med J 1983;287(6390):462.

36. Massin N, Bobadana AB, Wild P, Hery P, Toamain JP, Hubert J. Respiratory systems and bronchial responsiveness in lifeguards exposed to nitrogen trichloride in indoor swimming pools. Occup Environ Med 1998;55:258-63.

37. Ryznar Stability Index: the 3rd dimension needed for proper water balance. US Filter/Stranco 1999;1(1):1-3.

38. Australian Government Department of Health and Ageing, enHealth Council. Environmental Health Risk Assessment –guidelines for assessing human health risks from environmental hazards. Canberra, June 2004. Available at: http://www.nphp.gov.au/enhealth/council/pubs/pdf/envhazards.pdf (Cited 8 November 2012).

39. National Health and Medical Research Council (NHMRC), Natural Resource Management Ministerial Council. National Water Quality Management Strategy. Australian drinking water guidelines. 2011. Available at: http://www.nhmrc.gov.au/guidelines/publications/eh52 (Cited 8 November 2012).

40. National Resource Management Ministerial Council; Environment Protection and Heritage Council; Australian Health Ministers Conference. National Water Quality Management Strategy. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). 2006. Available at: http://www.ephc.gov.au/taxonomy/term/39 (Cited 8 November 2012)

41. NSW Department of Health. Rainwater tanks. Sydney: NSW Health, 2007. Available at: http://www0.health.nsw.gov.au/publichealth/environment/water/rainwater.asp (Cited 8 November 2012).

42. Australian Government Department of Health and Ageing, enHealth Council. Guidance on use of rainwater tanks. 2nd edition. Canberra, 2004. Available at: http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-document-metadata-env_rainwater.htm (Cited 2 November 2012).

43. Obsolete – reference deleted

44. Pool Water Treatment Advisory Group (PWTAG), Swimming pool water: treatment and quality standards for pools and spas. Micropress Printers, England, 1999.

Bibliography

American Public Health Association (APHA). Standard methods for the examination of water and wastewater, 17th ed. Washington, DC: 1989.

Barwic RS, Levy DA., Craun GF, Beach MJ, Calderon RL. Surveillance for waterborne-disease outbreaks--United States, 1999-2000. MMWR CDC Survell Summ 2000;49(ss04):1-35.

Beaglehole R., Bonita R, Kjellstrom T. Basic epidemiology. World Health Organization: Geneva, 1993.

Bell A, Guasparini R, Meeds D, Mathias RG, Farley JD. A swimming pool-associated outbreak of Cryptosporidiosis in British Columbia. Central Fraser Valley Health Unit, Maple Ridge, BC. Can J Public Health 1993;84(5):334-7.

Beneson AS, editor. Control of communicable diseases in man, 15th ed. Washington, D.C.: American Public Health Association, 1990.

Bernard AG. The microbiology of spa pools and the occurrence of folliculitis associated with spa pool use. Fisher Rare Book Thesis: University of Sydney, 1983.

Botzenhart K, Kampe A, Streib R. llnesses in relation to swimming pool visits – conclusions of a survey. Zentralbl Bakteriol Mikrobiol Hyg 1988;186(2):118-37 (In German).

Caldwell GG, Lindsey NJ,Wulff H, Donnelly DD, Bohl FN. Epidemic with adenovirus type 7 acute conjunctivitis in swimmers. Am J Epidemiol 1974;99:230-4.

Carpenter C, Fayer R, Trout J, Beach MJ. 1999. Chlorine disinfection of recreational water for *Cryptosporidium parvum*. Emerg Infect Dis 1999;5(4):579-83.

Casemore DP. Epidemiological aspects of human cryptosporidiosis. Epidemiol Infect 1990;104:1-28.

Cotor F, Zavate O, Finichiu M, Avram G, Ivan A. Entervirus contamination of swimming pool water; correlation with bacteriological indicators. Virologie1983;34(4):251-6.

Coulepsis AG, Locarnini SA, Lehmann NI, Gust ID. Detection of hepatitis A virus in the feces of patients with naturally acquired infections' J Infect Dis 1980;141(2): 151-6.

Dadswell J. Poor swimming pool management: how real is the health risk? Environ Health 1997;105(3):69-73.

D'Angelo LJ, Hierholzer JC, Keenlyside RA, Anderson LJ, Martone WJ. Pharyngoconjunctival fever caused by adenovirus type 4: report of a swimming pool-related outbreak with recovery of virus from pool water. J Infect Dis 1979;140(1):42-7.

Department of Health Western Australia. Code of Conduct for the Design, Construction, Operation, Management and Maintenance of Aquatic Facilities. 2004.

Deptartment of Health Queensland. Queensland Health. Swimming and Spa Pool Water Quality and Operational Guidelines. 2004.

Dupont HL. Shigella. Infect Dis Clin Nth Am 1988;2(3):599-605.

Dupont HL, Chappell Cl, Sterling CR, Okhuysen PC, Rose JB, et al. The infectivity of *Cryptosporidium parvum* in healthy volunteers. N Engl J Med 1995;332:855-9.

Engelbrecht RS, Weber MJ, Salter BL, Schmidt CA. Comparative inactivation of viruses by chlorine. Appl Environ Microbiol 1980;40:249-56.

Fewtrell L, Bartram J, editors. Water Quality: Guidelines, Standards and health: Assessment of risk and risk management for water-related infectious disease. World Health Organ Wat Ser.2001. IWA Publishing London.

Fields BS, Haupt T, Devis JP, Arduino MJ, Miller PH, et al. Pontiac fever due to *Legionella micdadei* from a whirlpool spa: possible role of bacterial endotoxin. J Infect Dis 2001;184(10):1289-92.

Ford A.L. The public health risks associated with swimming pools and spa pools within multi-residential apartment buildings – is there a need for regulation?' Sydney: University of Sydney, 2004.

Fox AB Hambrick GW Jr. Recreational associated *Pseudomonas aeruginosa* folliculitis. Report of an epidemic. Arch Dermatol 1984;120(10):1304-7.

Foy HM, Cooney MK, Hatlen JB. Adenovirus type 3 epidemic assoicated with intermittent chlorination of a swimming pool. Arch Environ Health 1968;17:795-802.

Furness BW, Beach MJ, Roberts JM. Giardiasis surveillance - United States, 1992-1997'. MMWR CDC Surveill Summ 2000;49(7):1-13.

Furtado GK, Adak GK, Stuart JM, Wall PG, Evans HS, Casemore DP. Outbreaks of waterborne infectious intestinal disease in England and Wales, 1992-1995. Epidemiol Infect 1998;121:109-19.

Ganloser G, Hasselbarth U, Roeske W. Treatment of swimming pool and bathing water'. Berlin, Beuth Verlag, 1999 (in German).

Geldreich EE. Sanitary significance of faecal coliforms in the environment. Water Pollution Control Research Series Pub. No. WP-20-3, UD Dept. of the Interior. FWPCA, USDI, Cincinnati, OH, 1966.

Geldreich EE. Bacterial populations and indicator concepts in faeces in sewage, stormwater and solid wastes. In: Berg G, editor. 1978:51-98.

Grobe S, Flemming HC, and Wingender J. Capability of mucoid *Pseudomonas aeruginosa* to survive in chlorinated water. Int J Hyg Environ Health 2001;204(2-3):139-42.

Harley D, Harrower B, Lyon M, Dick A. A primary school outbreak of pharyngoconjunctival fever caused by adenovirus type 3. Comm Dis Intell 2001;25(1):9-12.

Hellard ME, Sinclair MI, Fairley CK, Andrews RM, Bailey M, Black SC, et al. An outbreak of Cryptosporidiosis in an urban swimming pool: why are such outbreaks difficult to detect? Aust N Z J Public Health 2000;24(3):272-5.

Herwaldt BL, Craun GF, Stokes SL, Juranek DD. Waterborne-disease outbreaks. 1989-1990. MMWR. CDC Surveill Summ 1991;40(3):1-21.

Hoadley AW, Knight DE. External Otitis among swimmers and non-swimmers. Arch Environ Health 1975;30:445-8.

Hoehn RC. Comparative disinfection methods. J Am Wat Work Assoc 1976;69:302-8.

Hoff JC. Disinfection resistance of *Giardia* cysts: origins of current concepts and research in progress. In: Jakubowki, W, Hoff JC, editors. 1979:231-9.

Hudson PJ, Vogt RL, Jillson DA, Kappel SJ, Highsmith AK. Duration of whirlpool-spa use as a risk factor for *Pseudomonas dermatitis* and other bathing-associated infections. Infect Control 1985;6: 398-401.

Hunt DA, Sebugwawo S, Edmondson SG, Casemore DP. Cryptosporidiosis associated with a swimming pool complex. Commun Dis Rep CDR Rev 1994;4(2):R20-2.

Joce RC, Bruce J, Kiely D, Noah ND, Dempster WB, Stalker R, et al. An outbreak of cryptosporidiosis associated with a swimming pool. Epidemiol Infect 1997;107(3):497-508.

Kay D, Fricker C, editors. Coliforms and *E. coli*: problem or solution. International Conference on Coliforms and *E. coli*. Royal Society of Chemistry, 1995.

Kee F, McElroy G, Stewart D, Coyle P, Watson J. A community outbreak of echovirus infection associated with an indoor swimming pool. J Public Health Med 1994;16(2):145-8.

Keene WE, McAnulty JM, Hoesly FC,Williams LPJr, Hedberg K, Oxman, et al. A swimming-associated outbreak of hemorrhagic colitis caused by *Escherichia coli 0157:H7* and *Shigella sonnei*. New Engl J Med 1994;331(9):579-84.

Keswick BH, Gerba CP, Goyal SM. Occurrence of enteroviruses in community swimming pools. Am J Public Health 1981;71(9):1026-30.

Khabbaz RF, McKinley TW, Goodman RA., Hightower AW, Highsmith AK, Tait KA, et al. *Pseudomonas aeroginosa* serotype 0:9. New cause of whirlpool-associated dermatitis. Am J Med 1983;74(1):73-7.

King CH. Shotts EB. Wooley RE, Porter KG. Survival of coliforms and bacterial pathogens within protozoa during chlorination. Appl Environ Microbiol 1988;54:3023-33.

Kleinbaum DG, Klein M. Logistic Regression: A Self-Learning Text 2nd ed. London: Springer-Verlag, 2002.

Kramer MH, Herwaldt BL, Craun GF, Calderon RL, Juranek DD. Surveillance for waterborne-disease outbreaks – United States, 1993-1994. MMWR CDC Surveill Summ 1996;45(1):1-33.

Last JM. A dictionary of epidemiology. 2nd Ed. Oxford: Oxford University Press, 1988.

Lee SH, Levy DA, Craun GF, Beach MJ, Calderon RL. Surveillance for waterborne-disease outbreaks--United States, 1999-2000. MMWR CDC Surveill Summ 2002;51(8):1-47.

LeChevallier MW, Lawry CD, Lee RG, Gibbon DL. Examining the relationship between iron corrosion and the disinfection of biofilm bacteria. J Am Wat Works Assoc 1993;85:111-23.

Lemmon JM, McAnulty JM, Bawden-Smith J. Outbreak of cryptosporidiosis linked to an indoor swimming pool. Med J Aust 1996;165(11-12):613-6.

Levy DA, Bens MS, Craun GF, Calderon RL, Herwaldt BL. Surveillance for waterborne-disease outbreaks--United States, 1999-2000. MMWR CDC Surveill Summ 1988;47(5):1-34.

Luttichau H, Vinther C, Uldum SA, Moller J, Faber M, Jensen J. An outbreak of pontiac fever among children following use of a whirlpool. Clin Infect Dis 1998;26:1374-8.

MacKenzie WR, Kazmierczak JJ, Davis JP. An outbreak of cryptosporidiosis associated with a resort swimming pool. Epidemiol Infect 1995;115(3):545-53.

Mahoney FJ, Farley TA, Kelso KY. Wilson SA, Horan JM, McFarland LM. An outbreak of hepatitis A associated with swimming in a public pool. J Infect Dis 1992;165(4):613-8.

Mao JS. Yu PH, Ding ZS, Chen NL, Huang BZ, Xie RY, Chai SA. Patterns of shedding of hepatitis A virus antigen in feces and of antibody response in patients with nationally acquired type A hepatitis. J Infect Dis 1980;142:654-9.

Makintubee S, Mallonee J, Istre GR. Shigellosis outbreak associated with swimming. Am J Public Health 1987;77:166-168.

Martone WJ, Hierholzer JC, Keenlyside RA, Fraser DW, D'Angelo LJ, Winkler WG. An outbreak of adenovirus type 3 disease at a private recreation centre swimming pool. Am J Epidemiol 1980;111(2):229-37.

Martins MT, Sato MIZ, Alves MN, Stoppe NC, Prado VM, Sanchez PS. Assessment of microbiological quality for swimming pools in South America. Wat Res 1995;29(10):2417-20.

Mc Anulty JM, Fleming DW, Gonzalez AH. A community-wide outbreak of cryptosporidiosis associated with swimming at a wave pool. J Am Med Assoc 1994;272(20):1597-600.

McKenny J. Complete Swimming Pool Handbook. 2007 Macquatics On-site Training.

Mc Neill AR. Microbiological Water Quality Criteria: A Review for Australia. Australian Water Resources Council Technical Paper, No. 85. Canberra: AGPS, 1985.

MMWR. Shigellosis outbreak associated with an unchlorinated fill-and-drain wading pool--Iowa, 2001. MMWR CDC Surveill Summ 2001;50(37):797-800.

Moe C, Rhodes D, Pusek S,Tseng F, Heizer W, Kapoor C, et al. Determination of Norwalk virus dos-response in human volunteers. In: Proceedings of 98th Annual Meeting of the American Society for Microbiology, May 1998. Atlanta, GA.

Moore JE, Heaney N, Millar BC, Crowe M, Elborn JS. Incidence of *Pseudomonas aeruginosa* in recreational and hydrotherapy pools. Comm Dis Public Health 2002;5(1):23-6.

National Environmental Health Forum. Guidance on water quality for heated spas - National Environmental Health Forum Monographs Water Series No 2, 1996.

Pai CH, Gordon R, Sims HB, Bryon LE. Sporadic cases of hemorrhagic colitis associated with *Escherichia coli 0157:H7*. Ann Intern Med 1984;101:738-42.

Papapetropoulou M, Vantarakis AC. Detection of adenovirus outbreak at a municipal swimming pool by nested PCR amplification. J Infect 1998;36(1):101-3.

Pike E. Health Effects of Sea Bathing (EM 9511), Phase 111-Final Report to the Department of the Environment. WRC Report Number: DoE 3412/2. Medmenham, UK:Water Research Centre, 1994.

Porter JD, Ragazzoni HP. Buchanon JD, Waskin HA, Juranek DD. Parkin WE. *Giardia* transmission in a swimming pool. Division of Fields Services, Centers for Disease Control, Atlanta, GA 30333. 1998;78(6):659-62.

Price D, Ahearn DG. Incidence and persistence of *Pseudomonas aeruginosa* in whirlpools. J Clin Microbiol 1988;26:1650-4.

Pruss A. Review of epidemiological studies on health effects from exposure to recreational water. Int J Epidemiol 1998;27(1):1-9.

Ratnam S, Hogan K, March SB, Butler RW. Whirlpool-associated folliculitis caused by *Pseudomonas aeruginosa*: report of an outbreak and review. J Clin Microbiol 1986;23(3):655-9.

Rentorff RC. The experimental transmission of human intestinal protozoan parasites. II. *Giardia lambia* cysts given in capsules. Am J Hygiene 1954;59:209-20.

SAS, 1999-2001. SAS Institute Inc., Cary, NC, USA. SAS Proprietary Software Release 8.2 (TS2MO).

Schlech WF 3rd, Simonsen N, Sumarah R, Martin RS. Nosocomial outbreak of *Pseudomonas aeruginosa* folliculitis associated with a physiotherapy pool. Can Med Assoc J 1986;134(8):909-13.

Schiemann DA. Experiences with bacteriological monitoring of pool water. Infect Control 1985;6(10):413-7.

Schiff GM, Stefabovic GM, Young EC,Sander DS, Pennekamp JK, Ward RL. Studies of echovirus-12 in volunteers: Determination of minimal infectious dose and the effect of previous infection on infective dose. J Infect Dis 1984;150(6):858-66.

Sorvillo FJ, Fujioka K, Nahen B, Tormey MP, Kebabjian R, Mascola L. Swimming-associated cryptosporidiosis. Am J Public Health 1992;82(5):742-4.

Spitalny KC, Vogt RL, Witherell LE. National survey on outbreaks associated with whirlpool spas. Am J Public Health 1984;74(7):725-6.

Stafford R, Neville G, Towner C, McCall B. A community outbreak of Cryptosporidium infection associated with a swimming pool complex. Comm Dis Intell 2000;24(8):236-9.

Standards Australia 1995. Australian Standard Method 4276.3.1; 4276.6/7; 4276.12/13. Homebush Standards Australia

Sundkvist T, Dryden M, Gabb R, Soltanpoor N, Casemoore D, Stuart J. Outbreak of cryptosporidiosis associated with a swimming pool in Andover. PHLS Communicable Disease Surveillance Centre, London. Communicable Disease Report. CDR Rev 1997;7(12): R190-2.

Towner C, Marshall L. An outbreak of cryptosporidiosis associated with a Brisbane Aquatic centre. Environ Health Rev 1999.

Turner M, Istre GR, Beauchamp H, Baum M, Arnold S. Community outbreak of adenovirus type 7a infections associated with a swimming pool. South Med J 1987;80(6):712-5.

Warren IC, Ridgway J. Swimming pool disinfection. Water Res. Centre, Tech. Report 90, WRC, Medmenham, UK: 1978.

SHPN (EH) 130037