DISINFECTION PRACTICES FOR MAINTENANCE AND PROJECTS ON DRINKING WATER ASSETS

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ABSTRACT

A review of the disinfection C.t requirements during maintenance and project work on drinking water assets found inconsistencies across internationally recognised standards. The current study proposes a common approach of applying a C.t of 15300 mg.min/L based on 3 log *Cryptosporidium* inactivation. The study also identified improvements for the disinfection of filter media and emergent repair work in order to manage issues such as chlorine demand and the timely reinstatement of the asset. It also examined the challenges for implementation in a maintenance partnership including training, and the potential effect on equipment and system components.

INTRODUCTION

The risk of the pathogenic hazards entering the water supply during the performance of maintenance or project work on drinking water assets presents particular operational challenges. These include preventing the ingress of potential contaminants and the use of one of a variety of methods available for disinfection of the affected asset. This is particularly important after coagulation and separation processes in the treatment plant and in the supply system as there are often no further barriers to removing potential microbial contamination.

Standards for disinfection practices

There are a number of internationally reputable standards for disinfection practices to prevent microbial contamination of drinking water assets. The standards identified in the current study included:

- The American Water Works Association (AWWA) provides standards, some containing varying methods, for the disinfection of mains (C651) reservoirs (C652), and filtration media (C653 and B100 – for the supporting layers in a BAC/GAC filter). AWWA standards are accredited by the Amercian National Standards Institute (ANSI).

- The Australian standard ‘Plumbing and Drainage - Water services’ (AS/NZ 3500.1) provides a standard methodology for the disinfection of reservoirs (Appendix I) and mains (Appendix J).

- The Water Services Association of Australia, provides the ‘Water Supply Code of Australia’ (WSA-03) which includes the disinfection of mains (Appendix I).

- In the United Kingdom, the Water UK’s Technical Guidance Notes provides for the disinfection of new mains (TGN 2) and renovated mains (TGN 4 and TGN 6).

The methods within these standards typically includes the retention or spray application of a chlorine solution for a given contact time. Some methods, such as those in the Australian standard and water supply code are also reliant on flushing to achieve scouring or cleaning velocities before disinfection with chlorine occurs.

The inactivation of pathogens using chlorine

The resistance of some pathogens to chlorine at the concentrations normally present in distribution systems and the challenges to protecting public health are well regarded. Alternative disinfection techniques that can inactivate these pathogens include Ultra-violet (UV) irradiation and Ozonation. However, applying these in the disinfection of treated water assets is either difficult in practice or requires further investigation beyond the scope of the current study.

The Australian Drinking Water Guidelines (2011) identifies a number of pathogenic protozoa, such as *Cryptosporidium* and *Giardia*, that have a resistance to chlorine. The inactivation of *Cryptosporidium*, for example, requires chlorine concentrations and contact times much greater than those that can be practically used in drinking water supplies. Owing to their relatively large size, resistent protozoa can be removed by coagulation and filtration during treatment and possibly by scouring velocities during flushing. In contrast, bacteria and viruses are much smaller in size, but are sensitive to disinfection by agents such as chlorine.

The spray application, swabbing or retention methods where the resultant water is able to be disposed or removed from the drinking water supply system can allow the use of high concentrations of chlorine sufficient to inactivate pathogens such as *Cryptosporidium*.

Shields et al. (2008) propose a free chlorine disinfection C.t of 15300 mg.minutes/L at pH 7.5 as sufficient to inactivate *Cryptosporidium* to achieve a 3 log (99.9%) reduction in oocysts viability. Their study exceeds the Centres for Disease Control and Prevention (USA) which recommends C.t of 9600 mg.minutes/L for remediating recreational water venues following suspected diarrhea faecal incidents. However, the authors argue that their study differed from previous research as it was based on isolates from two different outbreaks. It showed that there was a greater resistance for oocysts from different geographic locations or those isolated from human outbreaks (compared with bovine origins).

Health Based Targets approach to sufficiently remove microbial contaminants

A number of water and public health organisations (for e.g., WHO (2011), WSAA (2015)) have proposed a Health Based Targets (HBT) approach to ensuring sufficient log-reduction of microbial hazards. Accordingly, various water sources are assigned a log-reduction requirement based upon how heavily they have been impacted by sources of microbial contamination including human and argicultural sources. The treatment required can then be determined with credit based on the log-reduction achieved by various processes within the treatment train.

The same approach can also be applied to supply system operations which have been impacted by human or environmental exposure such as maintenance works, main breaks or ingress by fauna. Mitigation by dilution in the system can also be considered. The 'treatment' required can then be determined including disinfection C.t.

A Water Research Foundation (2014) study found that flushing with particle fluidisation velocities of 2.5-3.0 ft/s (~1 m/s) should be used to remove particles that can shield micro-organisms. Credit for the removal of larger micro-organisms that could be considered particles, such as *Cryptosporidium*, may also be achievable by flushing with sufficient scouring velocities. Any remaining log-reduction required can also be achieved in-situ by treatment such as disinfection.

Maintenance and project works requiring disinfection processes

Maintenance and project works requiring disinfection include the repair or replacement of filters and filtration media, reservoirs, and mains. There are also specific requirements for pumps, hoses, tools and equipment, and underwater inspections by divers.

Implementing preventive measures requires training, input into maintenance schedules and the early stages of project planning, and sufficient practicality so that they can be applied to reactive maintenance work undertaken during incidents and emergencies. Accordingly, it is increasingly important for water service providers to understand the risks of contamination and to have fully implemented processes to ensure safe drinking water.

Scope and Limitations

This study critically examined a range of standards and practices used by water utilities for disinfection during maintenance and project work involving drinking water assets against the HBT-approach. The study then determined a consistent approach to applying disinfection including a disinfection C.t based on a conservative measure of the 3-log removal of *Cryptosporidium*. It also examined the potential credit that scouring velocities provide when disinfection is to be applied to mains.

The study followed the implementation of a series of disinfection procedures at Seqwater, the bulk water authority in South East Queensland, responsible for 35 treatment plants, an extensive bulk water supply grid and stand-alone systems that stretch across the region. Implementation of the procedures involved a number of challenges that would be faced by many water service providers including the complexities of a collaborative maintenance contract, operational sites that can only be offline for short durations to ensure continuity of supply, and difficulties achieving the targeted C.t due to the effect of excessive chlorine demand (e.g. filter media replacements).

The study proposes a number of opportunities to address these issues whilst adequately managing the risk of microbial contamination. It is limited to chlorine disinfection during tasks and the reinstatement of drinking water assets. It has not examined the use of alternative methods such as mobile ozone disinfection techniques.

METHOD

Determination of an appropriate disinfection C.t

The study began with the review of existing standards and literature on the inactivation of chlorine-resistant protozoa. This included a comparison of disinfection C.t in the relevant technical standards from the American Water Works Association (AWWA), Water Services Association Australia (WSAA) and the Water UK Technical Guidance Notes. Using this knowledge, the study proposed a disinfection C.t that could be effectively applied across a range of maintenance and project-related tasks. It then established procedures in seven distinct areas: small reservoirs, large reservoirs and reservoirs in chloraminated supply systems, mains, tools and equipment, pumps and hoses, underwater inspections, and filtration media.

Implementation of disinfection processes

A range of activities for the implementation of the new procedures was examined to identify opportunities for improvement. This included a review of: (1) the training of new and existing staff and contractors; (2) the equipment and chemicals required; (3) maintenance scheduling and the inclusion in existing work orders; and (4) project planning and business cases.

Adapting the procedures to manage challenges

The organisation's processes and procedures were adapted to address a number of challenges. This included: (1) Managing concerns that relatively high chlorine concentrations could detrimentally affect tools and equipment and polymer fittings such as reservoir liners, flow meter components and resilent seated valves; (2) The challenges when applying the procedures during reactive maintenance and emergency repair situations including opportunities for indicative microbial testing options when the 1-2 days required to obtain bacteriological assays is not available; and (3) Managing scenarios such as the disinfection for filter media, where chlorine demand was found to be excessive.

RESULTS AND DISCUSSION

Variations between disinfection standards

Disinfection C.t was found to vary significantly across the retention methods from 300-19200 mg.minutes/L (Table 1). Only the Water UK Technical Guidance Notes for retention methods exceeds the C.t of 15300 mg.minutes/L found by Sheilds et al (2008) to inactivate the most resistant strains of *Cryptosporidium*. AWWA methods only meet or exceed the C.t of 9600 mg.minutes/L consistent with the guidance from the Centres for Disease Control on the *Prevention on mitigating faecal contamination events in recreational swimming facilities*. Spray and swabbing applications appear to be consistently around C.t of 5000-6000 mg.minutes/L (Table 2) are well below both of these C.t targets, as are the retention methods that appear in the Australian standards and WSAA guidelines.

Methods that produce significantly low C.t suggest that the method is only intended to inactivate viruses and bacteria. Protozoan removal is either achieved physically through flushing, or mitigated through sanitary practices such as the use of dedicated clean equipment and the sealed storage of fittings. The problem with this approach is that pipes and fittings are often openly stored and are amenable to ingress by dust and vermin. It is also difficult to achieve the required flushing velocities in larger diameter mains (>DN 300).

Establishing a consistent disinfection approach

The worst case scenario for maintenance or project work was the ingress of wastewater or fauna. The same remediation would be required if the integrity of the asset can not be guaranteed. The Australian Guidelines for Water Recycling – Augmentation of Drinking Water Supplies (2008) provides the log reduction values required to protect public health when treating wastewater for potable re-use and these are shown in Table 3.

Table 3: Log Reduction Values for Potable Re-use of recycled water (AGWR (2008))

Bacteria	Viruses	Protozoa
8 log	9.5 log	8 log

In the context of a main break or inundation of a reservoir, these log reduction values represent an unlikely worst case scenario where the asset has been inundated with wastewater. In reality, dilution by drinking water already present or flushed through the asset and the removal of particles when flushing velocities can provide credit towards reducing the pathogen load. Table 4 provides proposed log reduction credits for dilution, flushing and disinfection.

Table 4: Proposed log reduction credits

Activity	Bacteria	Viruses	Protozoa
Impacted main break			
Dilution	3	3	3
Flushing*	0	0	3
Disinfection#	4	4	3
Total log reduction	**7**	**7**	**9**
Impacted reservoir			
Dilution^	5.5	5.5	5.5
Pressure spraying*	0	0	3
Disinfection#	4	4	3
Total log reduction	**9.5**	**9.5**	**11.5**

* Flushing (1 m/s) or pressure spraying
[#] Disinfection with a C.t of at least 15300 mg/L.
^ Dilution dependent on volume of spill/contamination and the affected reservoir/pipe

WaterRF (2014, Appendix D) modelled the log reduction for particle associated pathogens would be approximately 3 log when flushed at flow rates >3 feet/sec (e.g. 1 m/s) with three times the pipe-length volume. The use of positive pressure to avoid ingress and clean dedicated equipment during repair provides further risk mitigation. In an emergent situation, this could permit the use of more practical methods such as spray application without the need to achieve log reductions through flushing velocities.

Bacteria and viruses are not necessarily particle associated and therefore it has been assumed that there is no benefit in terms of log reduction from flushing other than dilution. The total log reductions in the main break scenario shown above (Table 4) are slightly less than the targets proposed in Table 3, but this was not considered significant as the maximum credit for disinfection was based on commonly applied metric of a C.t of 15 mg.minutes/L (e.g. WSAA (2014)); whilst the intent of this metric is to encourage the use of multiple barriers in a treatment plant, in the current study the log reduction is based on a C.t of 15300 mg.minutes/L which is three orders of magnitude higher.

Implementation of disinfection processes

The study examined the implementation of a series of disinfection procedures at Seqwater (Table 5), a bulk water supply authority.

Table 5: Typical disinfection procedures

Disinfection Procedure	Application
Tools and Equipment	Repairs/installations inside filters, reservoirs and mains. Repairing reservoir roofs, submersible remote controlled devices or boat entries.
Pumps and Hoses	Refurbished/replacement treated water pump. Suction pumps and hoses used to clean clear water ponds.
Water Mains	Water supply mains or valves being replaced or repaired. Methods for small and large sections and inundation scenarios
Bulk Water Supply Reservoirs	Cleaning sediment. Entry into reservoirs where the equipment is cleaned but cannot be disinfected. Reinstating a contaminated reservoir (e.g. intrusion by fauna).
Small Reservoirs in Free Chlorine Systems	As above, but for application within a small free chlorine system amenable to retention methods of disinfection.
Underwater Inspection and Work in Reservoirs	All industrial divers entering reservoirs.
Filters and Filter Media	Work on filters, underdrains or filtered water mains.

Training to improve risk awareness and demonstrate the disinfection processes promoted the use of the procedures and improved the behaviours of staff familiar with legacy practices. Implementation was further achieved by having prepositioned stores that were readily accessible at all treatment and supply system sites. The inclusion of disinfection requirements in business cases early in the planning processes was found to best support project management and situations where the contractor provided the necessary disinfection supplies.

Potential effects on tools and system components

The most significant concerns expressed by maintainers included the potential damage chlorine may have on their tools or elastomeric components that were to be installed. If tools and equipment can not be disinfected, then cleanliness practices still need to be maintained and the asset needs to be thoroughly cleaned and disinfected upon recommissioning.

The implementation of the disinfection of tools was found to be challenging, particularly when the tools are personally owned by the contractor undertaking the work. The risk of corrosion of the tools has been alleviated since the 2005 AWWA standard C651 was updated and the chlorine solution strength had decreased from 1%w/v (10,000 mg/L) without a specified contact time to 200 mg/L for 30 minutes. A procedure based on the proposed C.t of 15300 mg.minutes/L provides sufficient flexibility to also use concentrations around this lower level applied over a reasonable contact time (for e.g. 200 mg/L for 80 minutes or 600 mg/L for 26 minutes).

Another way of mitigating the risk of microbial contamination is to use new or dedicated clean equipment that has not been exposed to other maintenance tasks such as repairs on wastewater systems. The cost of having additional tool sets and equipment dedicated to treated water assets was particularly challenging in a business that also operates wastewater infrastructure and uses external contractors. This was managed by having firm disinfection procedures embedded in the organisation’s site access processes for application when new or dedicated tools and equipment can not be guaranteed. Items that cannot be disinfected such as safety harnesses, electrical tools, and elevated work platforms or are difficult to disinfect, for e.g. ribbed hoses, were either dedicated to the task and cleaned before entry or purchased new for the task.

The ability of elastomers used in resilient seated valves and polymers used in components such as reservoir liners and flow meters to withstand disinfection concentrations was also found to be a concern. It was found that most manufacturers are likely to only provide a warranty to normal concentrations in drinking water, presumably not greater than 5 mg/L of free chlorine. Interviews with a number of maintenance supervisors found no examples where chlorine used in disinfection practices caused noticeable damage. One exception was a reservoir liner that was found to have a 'tacky' appearance after disinfection with 1% chlorine solution; however this could be mitigated by reducing the solution strength and adopting a C.t based approached as mentioned earlier.

A view amongst the organisation's supply system engineers was that if a component is not resilient to higher levels of chlorine for a short period of time (e.g. 30-90 minutes), then doubts exist on whether it can tolerate 2-4 mg/L over the life of the asset which could extend to 10-15 years. Studies such as those by AWWARF (2007) completed accelerated trials on the strength of various elastomers in presence of elevated temperatures, chloramine and chlorine concentrations up to 60 mg/L. It is apparent in the curves that swell and stress/strain performance of the elastomers does not appear to begin to change until several to 10 days of exposure.

Access to disinfection equipment and chemicals

Accessibility to the equipment and chemicals required to adequately disinfect an asset before recommissioning was also found to be important to supporting adherence to the procedures. For this purpose, a disinfection equipment kit bag (Figure 1) was established at all water treatment plants and major sites within the supply system. Stocks of consumable items such as spray bottles and personal protective equipment (e.g. gloves) were also established within the organisation's regional stores. The issue and use of the equipment was embedded into the site access approval process whereby operational staff sign-off and approve access before work at their site can commence.

Figure 1: Example of a Disinfection Equipment Kit

A disinfection trailer (Figure 2) was also established in a centrally located maintenance hub. The trailer is capable of carrying 800 L water with a dosing pump and 300 L of sodium hypochlorite. A calculated dose up to 200 mg/L of free chlorine is able to be applied with the use of high pressure water sprayer. The system also has the ability to spay concentrated sodium hypochlorite directly if required. The trailer is fitted with tank level controls and a flow meter. The system was found to be capable of completing the spray application of disinfectant on the exposed walls and floor of a large reservoir, for e.g. Mt Crosby's 90 ML storages, without resupply.

Figure 2: Example of a Disinfection Trailer

Another challenge experienced was the access to fresh supplies of sodium hypochlorite from a reputable source. Sodium hypochlorite degrades with time to diminish in concentration as it forms the disinfection by-product chlorate. The storage of sodium hypochlorite under conditions that are hot or exposed to light will increase this degradation. Water treatment plants and re-chlorination facilities will manage their supplies so they are not introducing high levels of chlorate (for e.g., > 0.8 mg/L) into the water supply. However, plants that use chlorine gas for disinfection do not provide access to sodium hypochlorite and sources such as nearby pool shops can not guarantee chemical quality and correct storage. Accordingly, supplies for other plants, often a significant distance away, was required to be incorporated into the maintenance schedule.

A previous study internal to Seqwater on chlorate formation found that sodium hypochlorite degrades more for prolonged storage as a concentrated solution, in hot conditions and when new deliveries are repeatedly used to top up existing stocks or tank levels. Accordingly, storage of solutions for not longer than a week in refrigerated or air-conditioned storage was recommended for sites that do not have direct access to sodium hypochlorite tanks. Once used, stocks are disposed of to prevent the repeated topping up of containers with new on old solutions.

Challenges in disinfecting filtration media

The disinfection of filter media, including new replacement media, was found to be particularly challenging due to excessive chlorine demand. Whilst filter media does not have the visually obvious biofilm evident in assets such as old water mains, the massive amount of surface area on the sand particles was found to create a significant chlorine demand that needed to be eliminated in order to sustain sufficient chlorine concentrations for the necessary contact time.

Backwashing new filtration media several times to remove the fines was not sufficient to clean these surfaces. Additionally, sites that applied a single batch of high-chlorine solution were unsuccessful in keeping it above 15 mg/L consistent with the AWWA Standard, even when the process was repeated with higher starting concentrations. This demonstrated only regular replacement of the disinfectant solution or a continuous feed method that eliminates chlorine demand before any static retention period is required to complete filter media disinfection.

This challenge was managed at two of Seqwater's sites as shown in Figures 3 and 4 including (1) the backwash system at North Pine WTP and (2) filter to waste configuration at Noosa WTP.

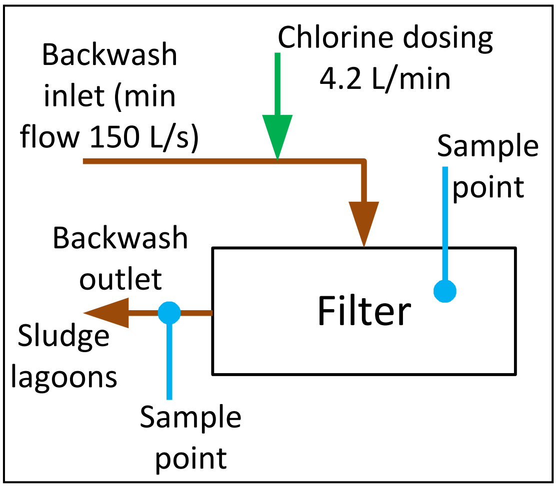

Figure 3: Continuous feed by backwashing

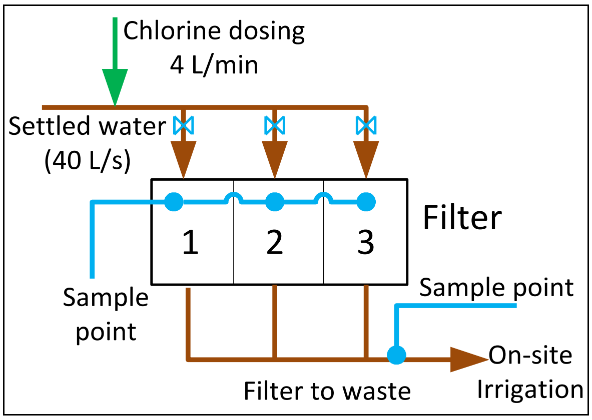

Figure 4: Continuous feed by filter to waste

In both instances, chlorine demand was eliminated within a few hours before the disinfectant solution was retained for a further 12 hours overnight. An example of depletion of the chlorine demand in a North Pine WTP filter is shown in Figure 5. In this example, the maximum chlorine dosing stroke rate was initially used, reduced to 75%, and then gradually increased to maximum again before an overnight retention period of 12 hours.

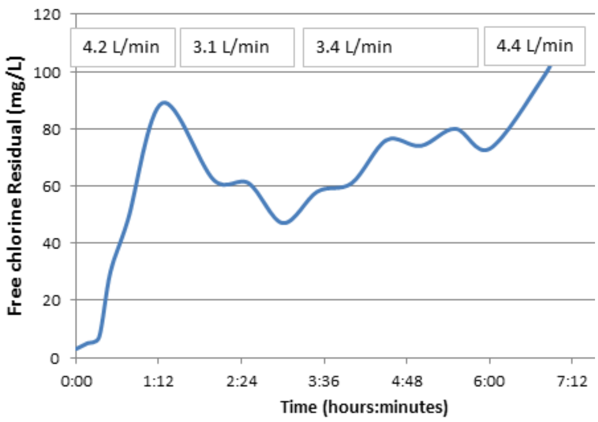

Figure 5: Typical Filter Media Chlorine Demand

Upon draining, chlorine residuals were measured. It was found that surface water below the media retained the chlorine concentration with little decay (>>100 mg/L); however, fractions within the media bed in contact with the finer particles and anthracite (obtained during drain down) were much lower (for e.g. 30-100 mg/L) but remained above 15 mg/L specified in the AWWA standard (Table 6).

Table 6: Filter media depth and chlorine residuals after 6 hours feed and 12 hours retention

Approximate fraction	Free chlorine residual (mg/L)
Top of filter (above media)	97-108
Top 0.3 m (anthracite and sand)	36-36
Centre 0.3 m (sand)	108
Bottom 0.3 m (sand-gravel)	167
Bottom of filter (under drains)	171

Challenges disinfecting supply mains

Large mains greater than DN300 have been found to be difficult or impossible in practice to achieve scouring velocities >1 m/s. Flushing and retention methods within significantly large mains need to ensure contact with all surfaces is achieved, otherwise thorough swabbing, wrapping or sealing needs to occur before installation. An additional challenge is the disposal of large quantities of chlorinated water due to environmental considerations. Off-site disposal has been achieved by extensive water tanker truck operations or the use of ascorbic acid to neutralise the chlorine on smaller projects. More often, preventing ingress in existing mains during periods of heightened risk is the best means of ensuring that an extensive disinfection process is not required for large mains. Examples include: isolating mains in low lying areas where air valves are present when flooding is expected, and maintaining positive pressure on a main break until the work area has been suction excavated and cleared.

Urgent reinstatement can also be affected by the turn around times for the results for microbial testing which can take 24-48 hours. Positive results can then require disinfection to be repeated. The use of rapid bacteriological quantification methods, such as Bactiquant™ or LuminUltra™, were found to support urgent recommissioning decisions required before laboratory results could be received. Samples need to be collected from upstream and downstream of the affected asset to provide a comparison that indicates changes in bacterial levels and whether the disinfection has been successful.

CONCLUSION

The use of a consistent C.t-approach to disinfecting assets provides assurance that safe drinking water will not be compromised by work on drinking water assets. A free chlorine C.t of 15300 mg.minutes/L will provide 3 log inactivation of *Cryptosporidium*, one of the most chlorine-resistant protozoa. The use of flushing velocities, positive pressure and clean dedicated equipment can further mitigate risk and contribute to achieving the total log reduction of contaminants, but needs to be used in combination with an effective disinfection C.t. Approaches such as continuous feed of the disinfectant, regular monitoring and rapid quantification methods for verification testing can support the process and decision making in emergent situations.

ACKNOWLEDGMENT

The authors acknowledge the support provided by Seqwater for completion of the study. They are thankful to Dr Arran Canning for his encouragement for an investigation into how the HBT-approach could be applied beyond water treatment processes and within the supply system operations.

REFERENCES

AS/NZS 1646:2007 Elastomeric seals for waterworks purposes, 2007, Standards Australia, Australian Government, Canberra, Australia.

AS/NZS 3500.1:2015 Plumbing and drainage - Water services, 2015, Standards Australia, Australian Government, Canberra, Australia.

Australian Drinking Water Guidelines, 2011, National Health and Medical Research Council, Australian Government, Canberra, Australia.

Australian Guidelines for Water Recycling (AGWR), 2008, Augmentation of Drinking Water Supplies, 2008, National Health and Medical Research Council, Australian Government, Canberra, Australia.

AWWA C651-05 Disinfecting Water Mains, 2005, American Water Works Association, Denver, Colorado, United States of America.

AWWA C652-11 Disinfection of Water Storage Facilities, 2011, American Water Works Association, Denver, Colorado, United States of America.

AWWA C653-13 Disinfection of Water Treatment Plants, 2013, American Water Works Association, Denver, Colorado, United States of America.

AWWA B100-09 Granular Filter Material, 2013, American Water Works Association, Denver, Colorado, United States of America.

AWWA Research Foundation (AWWARF), 2007, Performance of Elastomeric Components in Contact with Potable Water, pp. 71-149, AWWARF, Denver Colorado, United States of America.

Shields, J.M., Hill, V.R., Arrowood, M.J., and Beach, M.J., 2008, Inactivation of *Cryptosporidium parvum* under chlorinated recreational water conditions, Journal of Water and Health, 6(4), pp. 513-520, IWA Publishing, London, United Kingdom.

Water Research Foundation (WaterRF), 2014, Effective Microbial Control Strategies for Main Breaks and Depressurization, Report #4307a, Appendix D, WaterRF, Denver, Colorado, United States of America.

Water Services Association of Australia, 2011, Water Supply Code of Australia, WSA 03-2011, Version 3.1, Appendix I, Sydney, NSW, Australia.

Water UK, 2017, Principles of Water Supply Hygiene, TGN 2, 3 & 4, London, United Kingdom.

Water Services Association of Australia, 2015, Project Report Drinking Water Source Assessment and Treatment Requirements. Manual for the Application of Health-Based Treatment Targets WSA 202-2015-1.2., Melbourne, Victoria, Australia.

World Health Organisation (WHO), 2011, Guidelines for Drinking-Water Quality, 4th edition, WHO, Geneva, Switzerland.

Table 1: Differences in disinfection C.t between recognised standard methods for disinfection

Method	Application	Disinfection Process	C.t (mg.minutes/L)
AWWA C652-11 Method 1	Reservoirs	Retention of a free chlorine residual of 24 mg/L, held at not less than 10 mg/L for 24 hours.	>14400
AWWA C652-11 Method 3	Reservoirs	Fill to a level of 5% with a free chlorine residual of 50 mg/L for 6 hours, then filling to overflow with a residual not less than 2 mg/L for 24 hours.	Floor 18000 Walls >2880
AS NZS 3500 Appendix I	Reservoirs	Retention of free chlorine residual >10 mg/L for 6 hours if uniformly chlorinated by gas/chemical pump); for 24 hours if using mixed sodium hypochlorite.	>3600 >1440
AWWA C651-14 Continuous method	Mains	'Continuous feed' of water with a free chlorine residual of 10 mg/L applied for 24 hours.	14400
AWWA C651-14 Slug method	Mains	Retention of a 'slug' of water less than 100 mg/L, held at not less than 50 mg/L for 3 hours.	>9000
WSAA 03-2011 Appendix I	Mains	Retention of free chlorine residual >5 mg/L for 1 hour^ following initial cleaning by scouring/flushing.	300
AS NZS 3500 Appendix J	Mains >DN80	Retention of free chlorine residual >10 mg/L for 6 hours following initial cleaning by flushing >0.75 m/s,	3600
Water UK Technical Guidance Note 2	Mains	Application of a free chlorine residual of 20 mg/L for 16 hours.	19200
AWWA B100-09 AWWA C653-13	Filter media	Retention of a free chlorine residual of 25 mg/L, held at not less than 15 mg/L for 12 hours.	>10800

^ Concentrations must not be <2 mg/L with an appropriate contact time to provide a C.t of 5 mg.h/L.

Table 2: Differences between recognised standard methods for disinfection by spray application/swabbing

Method	Disinfection application	C.t (mg.min/L)
AWWA C652-14 Chlorination Method 2	Exposed surfaces in large reservoirs and reservoirs in chloraminated supply systems, tools and equipment, pumps and hoses with free chlorine 200 mg/L applied for 30 minutes	6000
AWWA C651-14 AZ/NZS 3500#	Disinfection of mains, fittings and fixtures by swabbing/spray application of free chlorine 200 mg/L applied for 30 minutes*	6000
AWWA C651-05*	Application of a 1% w/v sodium hypochlorite solution applied without any specified contact time. C.t shown represents a contact time of 5 minutes (e.g. before drying).	50000
Water UK Technical Guidance Notes 4 and 6	All replacement pipes, joints, fittings, and pipe cut ends should be spray disinfected with free chlorine 1000 mg/L solution. C.t shown represents a contact time of 5 minutes.	5000

AS NZS 3500 refers to C651 for disinfection practices during plumbing works as an alternative method.

** C651-05 is an example of an earlier version of AWWA C651 and is dated June 2005.*