Project 1117

Final Report

# Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk

## Second Edition

Collaborate Innovate Impact

# Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk

## Second Edition

Water for the wellbeing of all Australians
January 2020

**Research Project 1117**

# Disclaimer



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# Foreword

| | |
|---|---|
| Research Report Title: | Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk |
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# Acronyms

| | |
|---|---|
| ADWG | Australian Drinking Water Guidelines |
| ATP | Adenosine Triphosphate |
| AWWA | American Water Works Association |
| BAC | Biological activated carbon |
| BFPD | Backflow prevention device |
| Ct | Concentration and time required for a disinfectant to inactivate pathogens |
| CBHL | Clean bed head loss |
| CCP | Critical control point |
| DAF | Dissolved air flotation |
| FACE | Free available chlorine equivalent |
| GAC | Granular activated carbon |
| HACCP | Hazard Analysis and Critical Control Point |
| HBT | Health based target |
| HPC(22) | Heterotrophic plate counts measured at 22 °C |
| LRV | Log reduction value |
| NHMRC | National Health and Medical Research Council |
| NRMMC | National Resource Management Ministerial Council |
| NTU | Nephelometric turbidity unit |
| PAC | Powdered activated carbon |
| PDT | Pressure decay test |
| PID | Process and instrumentation diagram |
| PLC | Programmable logic controller |
| SCADA | Supervisory control and data acquisition |
| SCD | Streaming current detector |
| tBFPD | Testable backflow prevention device |
| TMP | Trans membrane pressure |
| USEPA | United States Environment Protection Agency |
| UV RED | UV reduction equivalent dose |
| VSD | Variable speed drive |
| WSAA | Water Services Association of Australia |
| WTP | Water treatment plant |
| WWTP | Wastewater treatment plant |

# Preface

There are many texts on the operation of water treatment plants (WTPs) (for example, Kawamura 2000; Logsdon et al 2002; Mosse and Murray 2009; Murray and Mosse 2008) and water supply systems (Mays 1999; AWWA 2004; Mosse and Deere 2009). There are also many regulatory documents that define good practice in water treatment (for example, USEPA 2006; Ministry of Health NZ 2018). Despite all this documentation and associated regulation, there are also many examples where the poor operation and maintenance of water treatment and supply systems has resulted in outbreaks of waterborne disease (Hrudey and Hrudey 2004; Hrudey and Hrudey 2014). The ongoing challenge seems to be how to convert the texts and regulations into improved operational practices.

The main purpose of this Guide is to provide managers and operational staff, that have the responsibility for the operation of drinking water supply systems, a concise reference document on the requirements for optimising the processes that are used to produce microbially-safe drinking water.

The information provided in this Guide represents current good practice and provides targets, both numerical and observational, which, if implemented, will achieve a reduction in microbial risk and help ensure the production of microbially-safe drinking water.

This is the second edition of this Guide. The second edition is a thorough rework of the original, with consideration of the many comments and reviews done by various organisations since the implementation of the first edition of this guide in 2015. Additional treatment unit processes have been included along with accompanying evaluation templates.

# Contents

**Foreword** ... 4
**Acronyms** ... 5
**Preface** ... 6
**Contents** ... 7
**Introduction** ... 8
Purpose of the Good Practice Guide ... 8
Catchment-to-Consumer Risk Management Principles ... 9
**Basis Of This Guide** ... 11
Basic Principles of Pathogen Risk Management in Water Treatment ... 11
Basic Principles of Pathogen Risk Management in Distribution System ... 11
Interpretation of the Table Entries ... 12
Assessment of a Water Supply System ... 12
Links to Other Documents ... 12
**Tables** ... 13
General Water Treatment Plant Operation ... 13
Raw Water Extraction and Storage Systems ... 17
Raw Water Flow Management ... 19
Wastewater Management ... 20
pH Alkalinity Adjustment ... 21
Oxidation ... 22
PAC Adsorption ... 24
Coagulation ... 25
Flocculation ... 28
Clarification ... 30
Media Filtration ... 32
Membrane Filtration ... 37
GAC/ BAC Filters ... 40
Ozonation ... 42
Chlorine-Based Primary Disinfection ... 43
UV Disinfection ... 46
Equipment and Instrumentation ... 47
Distribution System ... 50
Water Quality Information Management ... 57
**Appendix 1. Calculation Of $T_{10}$** ... 59
**References** ... 61

# Introduction

## Purpose of the Good Practice Guide

The catchment-to-consumer risk-based approach to the production of microbially-safe drinking water, which is detailed in the Framework for Management of Drinking Water Quality (the Framework) that underpins the Australian Drinking Water Guidelines (ADWG), is based on the identification and control of risks to the quality of drinking water supplied to consumers. This reduction in risk is achieved by implementing a multiple barrier approach, where a number of different barriers to contamination are put in place, from the catchment to the consumer. Whilst the risk management process stretches all the way from catchment to consumer, in practice the majority of risks are managed through the use of various water treatment processes.

Most Australian source waters require some level of treatment prior to being supplied to consumers as drinking water. The level of treatment required to produce microbially-safe drinking water will be a function of the quality of the source water and should be based on a system-specific risk assessment process that is consistent with the approach described under Element 2 (Assessment of the drinking water supply system) of the Framework.

The production of microbially-safe drinking water is difficult to consistently achieve, and requires constant vigilance, as well as well-maintained and operated water treatment processes (Element 3 Preventive measures for drinking water quality management and Element 4 Operational procedures and process control, of the Framework).

Within this risk-based approach, the purpose of this Guide is to provide concise advice on good practice preventive measures for the management of drinking water treatment processes and the distribution of this treated water to consumers. This is achieved by providing targets, both numerical and observational, for the various activities that should be undertaken in order to produce microbially- safe drinking water.

The Guide is not intended to be a risk assessment tool; it assumes that a system-specific risk assessment has been completed, and that the treatment and distribution processes that are present are suitable for the assessed level of microbial risk. The Guide is therefore focused on the optimisation, management and control of existing water supply systems. It also allows utilities to identify where there are shortfalls in their systems and thereby develop improvement plans to fill the identified gaps. The Guide includes proformas and templates to facilitate the evaluation of a system and identification of such gaps.

The advice in this Guide is applicable to existing water supply systems and is intended to help water utilities produce microbially-safe drinking water under existing arrangements.

The Guide is presented in a tabular format for simplicity. The table is broken into sections that relate to particular system processes and the critical areas of control in typical water treatment and distribution systems.

# Catchment-to-Consumer Risk Management Principles

The primary objective of any utility supplying drinking water to the public must be the provision of safe drinking water; that is, water that does not make the consumer ill. This objective is encapsulated in the Guiding Principles of the ADWG (NHMRC and NRMMC, 2011).

Illness caused by drinking water can be difficult to detect in most developed societies, but there is almost certainly an underlying level of illness that can be attributed to drinking water. However, when there are significant failures in barriers resulting in the contamination of drinking water, large scale illness can result (Hrudey and Hrudey 2004; Hrudey and Hrudey 2014). The consequences for consumers, water utilities and governments are severe.

Pathogens pose the greatest and most tangible risk to drinking water safety (NHMRC and NRMMC, 2011, Hrudey and Hrudey 2004; Hrudey and Hrudey 2014), making pathogen removal of paramount importance.

While chemical hazards such as cyanobacterial toxins are important, the primary treatment goal should be the removal and/or inactivation of viral, protozoan and bacterial pathogens.

The first barrier to pathogen contamination is source protection. Raw water destined for use as drinking water should be drawn from the best available source. The best available source would be a catchment area that is undisturbed and free of sources of contamination such as wastewater treatment plants, septic tanks, stormwater, and livestock, particularly cattle and sheep.

The reality is that many drinking water supplies are sourced from multi-use catchments that present numerous potential sources of pathogens. One of the primary goals for catchment managers is therefore to decrease the risk of pathogens, and particularly protozoan pathogens, entering the water courses in the catchment. A key management strategy is to work with landholders, natural resource management agencies, and other stakeholders to manage and reduce sources of microbial (and other) contamination.

Even with effective catchment management, there still exists a high probability that pathogens will periodically be present in source waters, either after a storm event, or as the result of some incident at a point source of contamination. Storm events also markedly change raw water quality, and these changes may exceed the capacity of existing treatment processes to produce microbially-safe drinking water. It is therefore important that the capabilities of existing water treatment processes are known, that early warning systems for changes in raw water quality are put in place and that treatment processes are only operated within their capabilities.

Another source of pathogen risk is where water treatment plant waste streams such as sludge thickener supernatant and backwash waste water are returned upstream of the water treatment plant. Appropriate management of these waste streams is an important component of pathogen source control.

After source water protection, the operation and maintenance of robust water treatment processes is the most effective management tool for preventing pathogens entering drinking water supplies. For each treatment process, and especially where the treatment process is identified as a critical control point, the following actions are required:

- establish target criteria andcritical limits for the treatment process;
- prepare and implement operational procedures and operational monitoring for the process;
- prepare corrective action procedures in the event that there are excursions in the operational parameters; and
- provide employee training to help ensure that the treatment process operates to achieve the established target criteria and critical limits.

Depending on what hazards are identified as part of the system-specific risk assessment, multiple barriers are generally required to control the different types of pathogens, for example media filtration and UV disinfection for protozoan pathogens.

The purpose and role of each treatment barrier must be clearly understood, and its relationship with the hazards being managed at that step in the process must be known. For example, chlorine disinfection does not inactivate *Cryptosporidium* oocysts, and has limited impact on *Giardia* cysts, due to the long contact time required to achieve the necessary C*t* values. Therefore, chlorine disinfection cannot be used as a sole treatment barrier where the water is sourced from multi use surface water catchments, or ground water sources under the influence of surface water. Such catchments are likely to contain protozoan pathogens.

Currently, pathogens cannot be measured by on-line analysis. Laboratory testing involves delays between sampling and the receiving of results, which makes it unsuitable as a process monitoring method. Furthermore, *E. coli* monitoring, with a turnaround period of 18 hours, forms part of verification monitoring, not operational process monitoring. Therefore, the only *practical* way to ensure the production of microbially-safe drinking water is to undertake monitoring of the operational performance of each process barrier.

Whilst a number of physical treatment processes are used to achieve microbially-safe drinking water, media filtration is one of the most commonly used in Australia. Therefore, media filtration will be used as an example to illustrate the monitoring of the operational performance of physical treatment processes.

Media filtration can be a very effective treatment barrier to the protozoan pathogens, *Cryptosporidium* and *Giardia*. Media filtration, following effective coagulation and flocculation, physically removes protozoan pathogens from the water. Adding a clarification step prior to the filters further improves pathogen removal. The effectiveness of this combination of processes is highly dependent on how well each of the unit processes is operated and maintained. For example, Risebro et al (2007) analysed 61 reports of waterborne illness and found 34 of the 61 were due to two events, specifically source water contamination and treatment system failures. Of the treatment failures, 90% were filter failures, many of which were chronic failures.

Currently, on-line monitoring of filtered water turbidity is the main *practical* way to continuously monitor the performance of a water treatment plant to optimise the removal of protozoan pathogens (UV monitoring also has a role where UV irradiation is provided). The ADWG recommends the use of online turbidimeters on each individual filter, and the reason for this is that the variation in performance between individual filters within a treatment plant can be significant. Several filters could comply with prescribed turbidity targets, while others may fail to meet the requirement by a significant margin. Such failure should prompt detailed investigation of these filters.

In general, the higher the turbidity, the higher the pathogen risk to consumers. Therefore, turbidity must be measured accurately and at a suitable frequency to be able to detect changes and introduce corrective actions before these changes create a risk to public health. Particles measured as turbidity also shield pathogens from the germicidal effects of subsequent chlorine or ultraviolet (UV) disinfection.

The final barrier in conventional water treatment is disinfection, using chemicals, such as chlorine, chloramine or ozone, and more recently, UV light.  These processes are also addressed in this Guide.

Even after the treatment processes at the water treatment plant result in the production of safe drinking water, once the water leaves the plant every effort must be made to ensure that recontamination does not occur within the distribution system. Waterborne disease outbreaks have been clearly attributed to the poor management of distribution systems (Ercumen et al. 2014, Nygard et al 2017).

# Basis Of This Guide

This Guide has been written based on the processes typically found in conventional water treatment plants, including chemical pH/ alkalinity adjustment, oxidation, PAC (powdered activated carbon) contact, coagulation, flocculation, clarification, media or membrane filtration, ozonation, GAC (granular activated carbon)/ BAC (biologically-activated carbon), disinfection (chlorine-based chemicals and/or UV irradiation) and wastewater management. It does not consider the dosing of fluoride which is typically covered in detail by Codes of Practice in each state.

Further, the Guide is based on the following assumptions:

1. The principles of the ADWG Framework for Management of Drinking Water Quality, as detailed in Chapter 3 of the ADWG (NHMRC and NRMMC, 2011), have been fully implemented and integrated into the operational practices of the water utility.
2. The water treatment plant is well designed, maintained and cleaned, such that the operation of the individual treatment processes is reliable.
3. Process monitoring is undertaken at appropriate intervals to inform operators of any changes to process parameters. The interval should be proportional to the possible rate of change of a parameter. For example, reservoir levels change only very slowly however turbidity in filtered water leaving a filter can change in a matter of minutes.
4. There is an informed and alert operations team, capable of responding rapidly to any changes within the water supply, treatment system or distribution system.

## Basic Principles of Pathogen Risk Management in Water Treatment

Studies of pathogen removal in water treatment plants have identified a number of high risk conditions and practices that can lead to a reduction in pathogen removal (Reduced Log Reduction Value (LRV)). These include:

1. Rapid increases in the concentrations of pathogens in the raw water source during storm events when surface runoff becomes contaminated with faecal material. The contaminated water then flows into the raw water. Such events are usually associated with an increase in the turbidity of the raw water.
2. Suboptimal coagulation (e.g. under- or over-dosing coagulant or incorrect coagulation pH).
3. Turbidity breakthrough across filters during ripening and particularly at the end of a filter run.
4. Poorly managed recycled waste streams (e.g. waste backwash water and sludge thickener supernatant) returned to the head of the treatment plant, or the reservoir supplying the plant, which can increase the load of pathogens coming into the plant.

## Basic Principles of Pathogen Risk Management in Distribution System

During distribution to the consumer, recontamination of treated drinking water can occur and pose a risk to public health (Ercumen et al 2014; Nygard et al 2007; Craun and Calderon 2001). The most common causes of recontamination are backflow, cross connections, and during repairs to water mains. Low pressure events in the mains also increase the likelihood of contamination from external sources. Faecal and other contamination can also occur directly in treated water storages as a result of mammals, birds, reptiles or amphibians gaining access through poorly designed or maintained tank and roof structures such as gutters, screens, hatches and overflow structures.

In the distribution system, the available chlorine residual may be insufficient to manage significant microbiological contamination. To manage this risk, recontamination must be prevented and adequate chlorine residuals maintained across the whole distribution system.

The risk of recontamination can be minimised by:

- ensuring the integrity of storage structures;
- the use of high quality and, where appropriate, testable backflow prevention devices, which are tested regularly;
- implementation of hygienic work practices;
- thorough flushing and disinfection after the installation of new mains, or when repair work has been carried out on existing mains, particularly where dewatering of the main has been necessary to undertake the repair; and

After installation of new mains, or after a mains break, water must not be returned to consumers until its safety has been assured.

## Interpretation of the Table Entries

Entries in the following Tables have been colour coded as follows:

| | |
|---|---|
| Red | A **Required** Measure that must be carried out to effectively manage the risks to the water supply |
| Amber | A **Supporting** Measure for one or more of the Required Measures |
| Green | A **Desirable** Measure |

Many of the **Required Measures** are infrequent requirements; that is, items that will be established or carried out during the initial optimisation of a treatment plant or even at the time a plant is designed and constructed. However, there are other **Required Measures** where regular assessment and reporting are required.

Consistent with the reporting requirements detailed in Chapter 10 of the ADWG, the results obtained as part of the drinking water quality reporting framework should be regularly reported to senior management, and potentially the Board. Such reporting provides high-level visibility on the performance of the water utility in managing microbial risk and ensures good governance with respect to the supply of safe drinking water.

It is also important to note that water suppliers can clearly demonstrate the adoption of good practice in water supply optimisation by implementing the *Required Measures.*

## Assessment of a Water Supply System

This Guide has been designed to allow utility staff to assess a water supply system by the provision of templates and proformas. A very well maintained and operated water supply system is expected to achieve a result of 85 % or more overall.

**It is recommended that a water utility review its water supply systems against this Guide once every two years (biennially). The reason for recommending a two-yearly interval is that if the Guide is used as intended, identification of deficiencies, but more importantly actioning the findings and implementing improvements, is likely to take more than 12 months for the utility. In keeping with the ADWG Framework (Element 11), it is further recommended to engage an independent expert approximately every 4 years to assess the system(s).**

It is recognised that large water utilities have a greater capacity to more easily achieve all measures, however the measures are designed to be achievable by all utilities.

Where this Guide and the associated assessment templates are used by a utility and a number of gaps identified, the suggested priority of improvement is in the order red then amber then green. Generally, the red measures have been listed in approximate order of priority, so that the higher measures within each table should be implemented earlier than those later in the list.

## Links to Other Documents

The Guide forms part of a suite of documents that provide advice on the production of microbially-safe drinking water.

The ADWG establishes the risk management framework for the production of safe drinking water.

The Water Services Association of Australia's (WSAA's) Manual for the Application of Health- Based Treatment Targets (HBT Manual) describes the steps to be taken to achieve microbially safe drinking water based on the application of LRVs. This Guide provides advice on how to achieve the treatment objectives set out in the HBT Manual.

The Guide can be used as a stand-alone document to assist in the optimisation of existing water supply systems, but it is preferable that it is read in conjunction with the ADWG and the HBT Manual.

# Tables

## General Water Treatment Plant Operation

### Introduction

Continuous operation of a water treatment plant maximises the removal of pathogens.

Ideally, during periods when raw water is of a consistent quality, a treatment plant will be run continuously, without changes to the flow rate or any other operating conditions for individual treatment processes. Operating in this mode, an optimised treatment plant will have the best opportunity to consistently produce safe drinking water.

However, ideal conditions often do not apply. In practice, it should be the aim of the Operations Team to run as close as possible to the ideal. Where every effort has been made to achieve continuous operation, but it cannot be achieved, particular care should be taken starting up a plant.

The plant needs to be operated, at least in part, during daylight hours to allow critical observation of the operating unit processes.

The operations team needs to be suitably trained and accredited and with sufficient tools (manuals and maintenance programs) to enable them to do their jobs well.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 1.1 | There are no interconnections between treated water and any raw or partially treated water. | Any actual or potential connection between fully treated drinking water and non-potable water should be fully isolated to prevent recontamination. | ***Biennially*** | Interconnections should be removed completely, and the ends blanked off. Alternately, a double block and bleed system can be installed with appropriate labelling and signage clearly stating such systems should only be opened when approved by senior management and with notification of the relevant health regulator. |
| 1.2 | Plant operation is continuous where possible.<br><br>Particularly for plants with conventional treatment (i.e. coagulation, flocculation, clarification and filtration) | All plants stabilise and produce better quality water with continuous operation.<br><br>Any plant with a clarifier sludge blanket, for example, will struggle with stop/start operation because as a result of each stop, the sludge blanket will settle and then need to be resuspended on start-up. This is usually associated with turbidity carryover and it can take several hours to achieve stable operation.<br><br>The hydraulic shock during plant start-up can produce significant turbidity spikes from the filters. This is notably worse when start-up occurs with filters well into their run time, with high head loss.<br><br>Continuous operation is less critical for membrane filtration plants as filtration is largely unaffected by stop/start operation. | ***Quarterly*** | Continuous operation can usually be achieved by:<br>• Reducing the flow rates through the plant<br>• Altering stop/start levels in treated water storage tanks<br>• Smart use of distribution storages to supply the daily demand patterns thereby limiting demand changes at the plant<br>• Reducing the numbers of process trains online at any one time<br>• Installing variable speed drives (VSDs) on raw water and treated water pumps<br>• Ensuring chemical dosing pumps are sized appropriately.<br><br>Where a treatment plant cannot achieve continuous 24 hour/day operation, plant runs should be as high as possible. Less than 6 hours is considered to be unsatisfactory. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 1.3 | Plant operators have received formal accredited training on all the unit processes employed at their treatment plants. | Training is essential for competent operation of a treatment plant | ***Annually*** | Training should be to a level of technical competency appropriate for the level of microbial risk at a particular plant.<br>Qualifications and competencies should be as defined by the National Competency Framework or relevant State requirements. |
| 1.4 | Plant operators have experience appropriate to the level of microbial risk managed by the plant. | Adequate experience is necessary to facilitate the management of a treatment plant during periods of change and in the solving of problems. Operators at higher risk plants require greater experience. | ***Annually*** | All staff operating water treatment plants have the experience and have maintained professional development as defined by the National Competency Framework or relevant State requirements to support their formal qualifications.<br>There are a number of online simulation packages that can facilitate gaining experience by solving operational problem scenarios. |
| 1.5 | The treatment plant is operated and attended for a significant part of its run time during daylight working hours | Plants run at night only or largely unattended are typically not as well operated and performance optimised as those that are more thoroughly attended and observed. | ***Biennially***<br>Or on system change | The treatment plant should be attended by a suitably qualified and experienced operator for sufficient time and at a sufficient frequency to be able to detect and diagnose any operational problems or deficiencies in the operation of the plant, and then investigate and implement solutions for these problems in a timely manner to ensure the ongoing production of microbially-safe drinking water. |
| 1.6 | All pits, pipes, valves, dosing points and sampling points, including the direction of flow in pipes, are clearly labelled.<br>Labelling should be consistent with plant PIDs and SCADA screens. | Poor labelling can create confusion and inappropriate actions during incidents, or when maintenance is being undertaken.<br>Labelling is also essential for the preparation of operating procedures and aids in the training of new operators. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Refer Australian Standard AS1345-1995 for labelling convention. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 1.7 | Where intermittent operation of a treatment plant is unavoidable, any dirty filter is backwashed prior to start up, or the filter is subjected to slow start-up or filter to waste is implemented. | Start-up of a heavily laden filter poses an unacceptable risk of turbidity and pathogen breakthrough unless filter to waste capability is in place and can waste the full production volume of water with a turbidity greater than the target for safe drinking water. | ***Quarterly*** | Any filter having accrued >75% of design terminal headloss should be backwashed prior to start up (AwwaRF 2002) or be subjected to slow start-up over a period of approximately 30 minutes (AWWA 2001).<br>Where operation is such that the plant only operates 2-3 days per week, then a backwash should occur prior to shutdown. |
| 1.8 | There is appropriate duty/standby capability provided for all critical components, such as chemical dosing pumps and backwash<br>pumps to allow the plant to continue to operate optimally. | Attempting to operate a plant with less than the necessary equipment, compromises pathogen removal. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | This could include uninstalled standby parts to enable quick changeover or replacement of equipment to allow rapid repair without compromising water safety or security of supply.<br>Critical items should have duty standby or enough spares to allow rapid repair without compromising safety or security of supply. |
| 1.9 | Flow split to downstream process units (flocculation bays, clarifiers and filters) is even. | Unequal flows can result in poor performance of individual process units. | ***Annually*** | Continuous monitoring using flow metering for individual process units allows accurate assessment of flow splits.<br>Flow splits should be within 5 % of the average (AWWA 2001). |
| 1.10 | A regularly updated Operating Manual or compilation of Standard Operating Procedures (SOPs) is readily available to operators and describes in detail the operation of the treatment plant. | A useful tool for any operations team, particularly during water quality incidents and emergencies is an up-to-date, informative Operating Manual. The manual should include current process and instrumentation diagrams (PIDs), plant hydraulic profile, detailed descriptions of how to operate the individual process units and a full trouble shooting section. | ***Continuously***<br>But in particular after any refurbishment or capital works.<br>Operators should be encouraged to regularly use and review the manual to ensure it is up to date. Regular meetings between operators to discuss and update is ideal. | New operators should be encouraged to use and challenge the manuals in discussion with experienced operators. The manuals should be modified in response to suggestions for improvement. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 1.11 | An up to date maintenance and renewals program is in place. This should include items such as replacement of filter media or membranes and UV lamps and assets throughout the distribution system. | A maintenance and renewals program allows for the systematic replacement and maintenance of critical equipment and consumables. This ensures equipment is able to operate near its maximum efficiency for as long as possible. | ***Annually*** | The program could be as simple as an excel spreadsheet that is regularly updated. There are many software packages available to make and maintain a maintenance program.<br>Regular feedback from trades and operators on the effectiveness of maintenance programs is critical and should be ongoing. |
| 1.12 | Filter outlet valve and level controls operate without hunting. | Hunting behaviour (continual changes in filter level and valve position) results in surges in flow through the plant and can result in particle shearing in filters and increased risk of pathogens passing through the filter. | ***Monthly*** | A suitable target is for each filter outlet valve position to operate within +/- 5% of setpoint. |
| 1.13 | Tank walls and channels are clean. | The build-up of sludge or biological growth, including algae, on structures in a treatment plant can compromise the operation of the plant particularly when it carries over on to the surface of the filters.<br>It can also compromise operation of online monitoring instruments. | ***As Required***<br>Based on regular observation | Tank wall and channel cleaning should be done as regularly as is necessary to avoid the build-up of sludge and/or biological growth.<br>If biological growth is significant, consider options like installing shades/sails or roofing to prevent sunlight which promotes growth. |
| 1.14 | Include protection for infrastructure where necessary to minimise weather, vermin and unauthorized personnel, | Vermin, birds and runoff into various tanks including flocculation, clarification and filtration tanks can lead to contamination. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Possibly include<br>• Roofing over flocculation tanks, clarifiers and filters<br>• Kerbs arounds flocculation tanks, clarifiers and filters<br>• Walkways that prevent ingress of water or other debris including from work boots<br>• Minimisation of roosting points for birds<br>• Stormwater diversion |

# Raw Water Extraction and Storage Systems

## Introduction

After rainfall, pathogens may wash into creeks, rivers and reservoirs, increasing the pathogen load entering the water treatment plant. The highest risk of contamination occurs during the first flush that follows a storm event at the end of an extended period of dry weather. During these periods of increased pathogen risk, operators need to be focussed and diligent to ensure best possible operation at each of the control points.

To further minimise the risk to consumers, an alternative water source, selective harvesting, or previously stored off-stream raw water should be used if available. Where this is not possible, the flow to the plant should be reduced for as long as possible until monitoring of raw water quality signals a return to more average operating conditions.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 2.1 | Early warning of changes in raw water quality is provided to treatment plant operators through online monitoring at the raw water offtake or higher in the catchment. | Early warning of changes in the nature and quality of the water entering the treatment plant allows time for appropriate actions to be taken by the operations team.<br><br>In a run of river system, development of communication protocols with treatment plants further upstream can also provide early warning of changes. | ***Biennially***<br><br>Regular meetings or discussions (typically quarterly) relating to raw water trends and microbial water analysis are also recommended | Monitoring typically includes turbidity, true colour, $UV_{254}$, pH, conductivity, rainfall and river flow.<br><br>In the case of reservoir monitoring, phosphorous, redox, temperature and dissolved oxygen (DO) can provide early warning of turnover events. Chlorophyll-*a*,phycocyanin or phycoerythrin monitoring and satellite imagery analysis may also be useful.<br><br>Appropriate actions in response to poor raw water quality include:<br>• Jar testing and subsequent adjustment of chemical dosing rates<br>• Down rating (i.e. reducing flow) or stopping the plant<br>• Utilising alternative water sources<br>• Filling off-river, raw water storages or treated water storages |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 2.2 | Where alternative sources or alternative offtakes are available, the most suitable raw water source/offtake is used at all times. | The most appropriate raw water should be selected based on chemical parameters including DOC or $UV_{254}$, the likely pathogen and cyanotoxin load, and the treatability of the water. | ***As Required***<br>The monitoring interval should be based on the rate at which the raw water quality at a particular source can change. | Regular monitoring of alternative sources or alternative offtakes allows the most suitable raw water to be identified and used for treatment.<br>Jar testing will assist in determining the treatability of water from different sources. |
| 2.3 | Raw water extraction points and their immediate locale, including intake screens are regularly inspected for sources of contamination and findings recorded. | Inspection allows identification of contamination sources. | ***Quarterly***<br>Intake screen cleaning should occur more frequently during periods of poor raw water quality. | Formal records confirm inspection and timely management of any potential sources of contamination. |
| 2.4 | Bore heads are fully sealed and the bore casings are regularly inspected and findings recorded. | Inspection allows identification of the potential for contamination. | Older casings should be inspected more frequently than new casings. 5 to 10 years is a suitable interval for casing inspections | Bore integrity should be included in the inspections and any flooding risk minimised.<br>Formal records confirm inspection and timely management of any potential sources of contamination. |
| 2.5 | Travel time of raw water from the source to the treatment plant is known for typical plant flows. | Knowing the actual time that a change in raw water quality will take to reach the treatment plant allows the operations team to accurately plan and prepare for the changes. | ***Biennially***<br>And after any refurbishment or capital works. | Preparation of a flow vs travel timetable or relevant information included in an Operating Manual. |
| 2.6 | Detention time in raw water storages is maximised and short circuiting is minimised by careful positioning of the inlet and outlet or installation of baffles. | Pathogen load can be reduced using the natural processes of settling and UV disinfection (Toze et al 2012; and Hipsey et al., 2003 & 2005). | ***Biennially*** | In large storages, long detention times can encourage growth of blue green algae. Alternative strategies may need to be implemented at different times. |

# Raw Water Flow Management

## Introduction

Changes in flow rate affect all aspects of a water treatment. Chemical dosing must be adjusted in proportion to any flow rate change. Increasing flows to a clarifier typically leads to billowing and carryover of floc, which in turn increases the load on the filters. Increasing flow rates to a filter results in particle shedding from the filter which represents an increased risk of exposure of consumers to pathogens. This is not so relevant for membrane filters.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 3.1 | Raw water flow rate increases at start up, or during operation are <3% per minute with a critical limit of 5% (AwwaRF 2002). | Significant flow rate increases can lead to particle shedding in filters with the associated risk of increased passage of pathogens. This is more critical at higher filter loading rates and at the end of filter runs.<br><br>Rapid changes in flow rate may also adversely impact on clarifiers and possibly disinfection and chemical dosing systems. | ***Quarterly*** | For example, if plant flow is 40 L/s, the increase should occur at no more than 1.2 L/s per minute. Therefore a 50% increase in flow would take approximately 16 minutes to implement.<br><br>The adverse impact of flow rate changes can often be seen with turbidimeters but certainly with particle counters.<br><br>Weak floc is more susceptible to rate changes.<br><br>All flow rate changes should be recorded. |

# Wastewater Management

## Introduction

The reuse of waste streams such as spent backwash water and/or supernatant from clarifier sludge thickening, without adequate treatment, increases the risk of protozoan pathogens passing through the treatment plant. Therefore, such recycled water must be carefully managed to minimise any impact on the performance of the plant.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 4.1 | Any water returned to the head of the treatment plant occurs upstream of all processes designed to remove solids from the raw water, in particular coagulant dosing. | Waste streams require full treatment to minimise pathogen and other water quality risks.<br>Coagulation cannot be optimised if the return point is after the point of coagulant addition, or if the return is intermittent. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Recycling the full wastewater stream without any treatment (settling as a minimum) increases the risk of pathogen and contaminant breakthrough.<br>In high risk catchments, or during high risk periods, water treatment residual supernatants should not be returned to the head of the plant if practicable. |
| 4.2 | Any return is well mixed with the raw water entering the plant (AWWA 2001). | The raw water and recycled water streams must be well mixed to ensure a single raw water type with uniform characteristics is achieved prior to any coagulation. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 4.3 | The coagulant dose is adjusted for the additional flow and load to ensure coagulation remains optimised. | Optimised coagulation for the full raw water flow including recycled water streams is essential to minimise risk. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 4.4 | The flow rate of return streams to the head of the plant is continuous with a target <5% of inflow and a critical limit <10% of inflow (AWWA 2001) (USEPA 2002). | Intermittent return flows make it very difficult to optimise coagulation and create a high risk of pathogen breakthrough. | ***Annually*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 4.5 | The turbidity of any wastewater recycle is monitored and the recycle shut down if it exceeds a set point. | Recycled water from waste streams is likely to have an increased pathogen load derived from degraded floc/sludge.<br><br>Elevated turbidity increases the difficulty of effectively treating any waste stream. | ***Annually***<br><br>And after any refurbishment or capital works. | Typically shut down is set at between 10 and 20 NTU with alarms in place before shutdown limit is reached. |
| 4.6 | In high risk catchments, sludge from the clarification step is directed to sewer or otherwise removed, or the supernatant is treated prior to any recycling. | Recycled water from sludge handling in a treatment plant in a high-risk catchment is likely to contain a higher concentration of pathogens. The supernatant water is therefore unsuitable for return without treatment. | ***Biennially*** | Appropriate treatment may be ultraviolet (UV) irradiation, oxidation and/ or filtration. |

# pH Alkalinity Adjustment

## Introduction

pH or alkalinity adjustment is required for successful coagulation, oxidation and disinfection. pH optimisation for particular processes are covered under Oxidation and Coagulation below. Alkalinity adjustment may also be used for coagulation optimisation and for the control of the corrosivity of the treated water.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 5.1 | Sufficient dilution, mixing and contact time is provided for any chemicals dosed. | Any chemical reaction (oxidation or coagulation) requires uniform pH for complete reaction with uniform formation of particulates and floc. | ***Design Review***<br><br>***Biennially thereafter***<br><br>And after any major refurbishment or capital works. | Typical chemicals used include: lime, soda ash, caustic soda and carbon dioxide.<br><br>The chemicals should be well mixed with the water prior to any unit process. Typically a dilution ratio of at least 10:1 is preferred. |

# Oxidation

## Introduction

An oxidation step is required for the oxidation of soluble metals (especially iron and manganese) to particulates for subsequent removal via coagulation, flocculation, clarification and filtration. This step may also oxidise organic compounds which can assist in their removal but can also produce unwanted by-products.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 6.1 | The technical basis for determining the ratio of oxidant to contaminant metal has been established for a given raw water. | While there are theoretical ratios available in the literature these tend to vary in practice due to bound organics and other contaminants in the raw water. Higher and sometimes very much higher ratios are usually required. | **Annually**<br>And after significant changes in raw water quality or after storm events | For example, using potassium permanganate, the theoretical ratios are 0.94:1 for removal of iron and 1.92:1 for removal of manganese but practical ratios may be as much as 5 times higher due to the presence of organics. |
| 6.2 | Sufficient contact time is provided for oxidation. | For complete or near complete conversion of soluble metals or other compounds sufficient contact time is required. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Contact time may be in pipe, channel or tank.<br>The shortest contact time is typically required for ozone, followed by potassium permanganate, chlorine dioxide, chlorine and oxygen.<br>At design flow effective contact time (contact time x baffle factor) may vary between 3 and 60 minutes depending on the oxidant used and the pH and temperature. |
| 6.3 | Dosing of oxidant is well controlled to the setpoint. | Under or over-dosing of oxidant can lead to the contaminant, or in some cases the oxidant itself, passing through the treatment process and the production of coloured water. | ***Weekly*** | Target low metals concentration after filtration. Typically, less than 0.02 mg/L for manganese, but preferably less than 0.01 mg/L to minimise complaints. Iron levels should be below 0.05 mg/L.<br>Regular measurement of iron, manganese and DOC where required.<br>Feedback control on chlorine, ozone residual or pH.is preferred. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 6.4 | Required pH for oxidation is maintained. | Oxidation can be highly sensitive to pH and should be optimised for the treatment objectives. | ***Quarterly*** | Satisfactory oxidation may occur over a broad pH range. The more optimum the pH the less contact time is required.<br><br>Continuous online monitoring of pH is preferred.<br><br>Operations staff need to manage competing pH requirements through the process. For example, the optimum pH for manganese removal is typically high and may be in conflict with pH requirements for coagulation. |
| 6.5 | Manganese and iron removal is optimised by monitoring throughout the treatment process. | Feedback on the metals concentration(s) after filtration is necessary to determine the effectiveness of applied dose. | ***Online or daily manual sample*** | Both soluble and total metal concentrations should be measured at multiple points through the treatment process. For example<br>• Raw water<br>• Clarified water<br>• Filtered water<br>• Final treated water.<br><br>Multiple measurements during the day may be necessary. |

# PAC Adsorption

## Introduction

PAC adsorption is provided to adsorb and remove (via coagulation clarification/filtration) organic contaminants including taste and odour compounds (typically MIB and geosmin) and algal toxins. While this section does not relate specifically to management of microbial risk it is included for completeness.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 7.1 | Sufficient contact time and mixing is provided for adsorption of contaminants by the PAC. | For satisfactory removal of organic contaminants, sufficient contact time is required. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | A contact tank with sufficient mixing to suspend the PAC is preferred. Dosing into raw water pipelines is another option but note that PAC is abrasive and may damage any fittings or instruments in the pipeline. PACs available are coal, wood or coconut based and have various adsorption capacities as reflected by their iodine number (the higher the better). Tannin and methylene blue numbers may also be used. Coal based PAC is most commonly used and covers a broad range of organic contaminants.<br>As a general guide, at design flow, at least 15 minutes and preferably 30 to 60 minutes of effective contact time is required depending on the organic contaminant to be removed.<br>It is important to note the variable performance of some PACs and this should be investigated as part of the selection process and in determining adequate contact time. |
| 7.2 | A monitoring protocol is developed for organic contaminants in raw and treated water to determine the need for PAC dosing and its effectiveness when dosed. | Feedback on when dosing is required and optimising dose to be applied requires regular monitoring of contaminants in both the raw and treated water. | ***Frequency should be in line with blue green algae management protocols*** | Typically, PAC is over dosed and sometimes a low dose is continually applied particularly during the summer months.<br>The effectiveness of the dose rate to remove organic contaminants should be confirmed by testing the treated water. |

# Coagulation

## Introduction

Coagulation is the essential first step to minimise the passage of pathogens through a treatment plant. Maximum pathogen removal requires optimised coagulation at all times.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 8.1 | A well-designed mixing system (static or mechanical) is provided for coagulant mixing. | Optimised coagulation is absolutely dependent on rapid and thorough mixing of the coagulant and the raw water. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Well-designed mixing systems vary between flash or rapid mixers (inline or in tank) of various designs to static mixers or long sections of pipe with sufficient bends and fittings. |
| 8.2 | Appropriately sized, graduated calibration tubes, calibrated flow meters or mass flow meters are provided to measure the amount of coagulant or flocculant dosed (AwwaRF 2002). | Accurate dosing of coagulant is essential to maintain optimised coagulation. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Calibration tube size should be such that in one minute, the liquid drops a distance at least equal to the diameter of the tube. |
| 8.3 | There is a system to detect the loss of coagulant dosing, including carrier water. | Compromised or failed coagulation results in reduced pathogen removal.<br>In systems where carrier water is added at the dosing skid, a loss of carrier water can result in under dosing. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Methods of detection include:<br>• Flow meters and flow switches<br>• Streaming current detectors or zeta potential meters<br>• pH meters<br>• Level sensors in storage tanks<br>• Variation of pump speeds required to deliver the required dose. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 8.4 | Optimum coagulation pH for inorganic coagulants is determined and the coagulant pH is controlled within the desirable pH range for the specific coagulant. | Coagulation can be highly sensitive to pH and should be optimised for the treatment objectives. | ***Weekly*** for run of river plants.<br>***Quarterly*** for reservoir plants. | pH should be within the required range 95% of the time. For alum this is likely to be +/-0.2 pH units.<br>The pH at which coagulation is optimised may be affected by the temperature and the target should be adjusted, accordingly. |
| 8.5 | Volumetric or draw down checks of the coagulant dose rate are performed, and the dose is verified. | The actual dose delivered should be checked to ensure optimised coagulation is maintained. | ***Weekly***<br>**Biennially**<br>For a system with a flowmeter. | The coagulant dose should be within +/- 5% of the setpoint 95% of the time |
| 8.6 | Chemical dosing is flow paced. | The dose of coagulant is critical to the success of the coagulation process and must be accurately and proportionally maintained at all flow rates. | ***As required*** | Volumetric draw down checks should be undertaken regularly and at different flow rates to confirm accuracy. |
| 8.7 | Dilution of coagulant with carrier water is at least 10:1, and preferably less than 20:1 or according to the manufacturer's specification. | Dilution assists the even dispersion and mixing of coagulant which is essential for optimised coagulation. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Over-dilution can compromise coagulation.<br>Addition of carrier water at the discharge of the coagulant dosing pump or at the inlet of the static mixer is preferable to reduce static mixer blockages. |
| 8.8 | The order of chemical addition has been optimised for coagulation, with sufficient time between each addition to allow for the completion of the chemical reaction process. | The order of chemical addition is important to achieve all treatment goals (Murray and Mosse 2008). In most cases the order is: pH correction, coagulant, coagulant aid. | ***Biennially***<br>And whenever a new chemical is introduced or there is a significant process change. | Many treatment processes are compromised by incorrect sequencing of chemicals and/or insufficient time for the reactions to take place. |
| 8.9 | Regular jar testing is carried out. | While the interval for jar testing is likely to be plant-specific, infrequent jar testing results in loss of competency as well as incorrect dosing. | ***Fortnightly*** for run of river plants.<br>***Monthly*** for reservoir plants. | More frequent jar testing will be required during periods of change.<br>Records of jar testing confirm application and are a useful reference. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 8.10 | Post-coagulation concentration of soluble Aluminium (Al) or Iron<br><br>(Fe) is <0.1 mg/L (Murray et al. 1999). | Low levels of coagulant metals confirm optimised coagulation (pH, alkalinity and coagulant dose and type), while higher results indicate sub optimal coagulation. | **Fortnightly**<br><br>And after a change in coagulant dose. | Testing is most easily carried out on water leaving the filters.<br><br>The target can be as low as 0.05 mg/L in fully optimised treatment plants. |
| 8.11 | Where instrumental control or software control is not in place, operators respond proactively to changed raw water conditions using a look up table or other tools (alum and polymer doses related to raw water turbidity, DOC, colour and temperature) (AwwaRF 2002). | During changing conditions, rapid responses are necessary to avoid unsafe water leaving the treatment plant. | **As Required**<br><br>**Event based -** Review of dosing tables and response plans following events and periodically. | |
| 8.12 | Operators respond proactively to changed raw water conditions using instruments (Streaming Current Detector, Zeta Potential or spectroscopic systems) (AwwaRF 2002). | During changing conditions, rapid responses are necessary to avoid unsafe water leaving the treatment plant. | **Continuously** | Regular checks and maintenance are required to ensure any instruments are accurate and working reliably. |

# Flocculation

## Introduction

The flocculation stage should produce a uniform even floc of an appropriate size for the following clarification or direct filtration step.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 9.1 | Turbulence after the formation of floc is minimised (AwwaRF 2002). | Post flocculation turbulence can cause floc shearing. Floc generally reforms poorly once it is disrupted and may result in higher filtered water turbidity and higher pathogen risk to consumers. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 9.2 | Flocculation time is between 5 and 45 minutes depending on water temperature. | Water temperature has a significant effect on flocculation. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | The critical transition temperature between slow and faster flocculation is typically around 10-12$^{O}$C.<br>A table showing flow vs flocculation time should be included in the Operating Manual. |
| 9.3 | Flocculation tanks are kept free of accumulated compacted sludge at the bottom of the tanks or settled sludge on launders or collection pipes. | Sludge accumulation results in a reduction of the floc basin size and therefore flocculation time. There is also a risk of potential carryover of anaerobic "lumps" to the filters on start-up. | ***Quarterly*** | Records confirm inspection and any action taken. |
| 9.4 | For gravity systems, large settleable floc (1.5 to 5mm) is present.<br>For DAF systems, medium floc (0.5 – 1.0mm) is present.<br>For direct filtration, small pin floc <0.3mm is present. | Maximised solids removal in the clarification step minimises the subsequent load on the filters and requires appropriately sized floc. | ***Daily*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 9.5 | Flocculators run continuously (24/7), even during plant shutdown (AWWA 2001). | Intermittent operation allows settling of floc and compaction which increases the risk of carryover of material to the filters on start-up.<br><br>Continuous flocculation allows the treatment plant to return to optimum operation after start-up more quickly. | ***Weekly*** | |
| 9.6 | Uniform floc is present in a clear water background (not hazy or cloudy) leaving the flocculation zone (AwwaRF 2002). | Uneven floc size, or a muddy/turbid background indicates poor coagulation and/or poor flocculation which may result in reduced pathogen removal. | ***Daily*** | Mixing speeds can affect floc formation. Consider adjusting flocculation speed with changes in season, particularly in obvious changes in water temperature to avoid breaking flocs |
| 9.7 | In DAFF after a backwash, air saturated water is reintroduced to the chimney before flow to the filters occurs. | Flocculated water entering the plant prior to DAF results in settling of floc on the surface of the filter rather than flotation. | ***Monthly*** | |

# Clarification

## Introduction

This is the primary solids and pathogen removal step. Typically, around 90 % of floc removal occurs during clarification.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 10.1 | The design surface loading rate of the clarification system is known, and the plant operates within the design specifications. | Not adhering to the design specifications is likely to result in poorer performance of the process element and consequently poorer pathogen removal. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 10.2 | The clarification process step is identified as a control point and controlled within defined targets and limits. | Consistent, optimised performance of the clarification system reduces the load on the filters allowing longer and stable filter run times and improved pathogen removal. | ***Quarterly*** | Murray and Mosse (2009) provide targets <1 NTU with a maximum of 5 NTU for conventional clarification and note that DAF can achieve significantly <1 NTU but a maximum of 3 NTU is recommended.<br>Online monitoring is recommended.<br>The limits should be reflected in alarms for this process step. |
| 10.3 | Solids contact and sludge blanket clarifiers are not subjected to stop/start operation. | Stop/start operation allows for the settling of sludge and results in poor operation of the clarifier after start-up. | ***As required*** | Solids contact clarifiers can be operated intermittently, if the mixers/impellors remain on continuously.<br>Continuous operation of clarifiers also helps minimise issues caused by clarifier boil-ups, particularly in winter months. |
| 10.4 | In DAF, the distribution of fine bubbles is such that milky water extends uniformly across the full width of the tank and at least half of the length of the tank. | A dense even distribution of fine bubbles ensures maximum removal of floc and therefore minimum floated water turbidity. | ***Weekly*** | The bubble distribution should be observed at different times during the day. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 10.5 | Online turbidity meters (complying with USEPA 180.1 or ISO 7027) are provided for each individual clarifier or DAF. | Continuous monitoring of clarified water turbidity can provide early warning of problems with coagulation, flocculation or clarification and reduce the likelihood of filter failure. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 10.6 | For DAF, the increase in level in the tank to bring about removal of the float is kept to an absolute minimum. | Increases in level result in increased hydraulic head and cause turbidity spikes in the filtered water | ***Monthly*** | Small amounts of float lapping over the weir is better than operating with the water level several centimetres below the weir. |
| 10.7 | DAF float off or mechanical removal results in >90% removal of the float. | Float retained on the surface of DAF can result in sludge falling onto the surface of the filter. | ***Monthly*** | |
| 10.8 | For DAF, all cutting sprays are operational and correctly adjusted to release the float from the walls. | Float retained on the surface of DAF can result in sludge falling onto the surface of the filter. | ***Monthly*** | Poor float removal also results in excess water wastage during desludge. |
| 10.9 | Uniform fine floc in a clear water background (not hazy or cloudy) leaving the clarifier or on top of the filters (AwwaRF 2002). | Large floc size or a muddy/turbid background in a clarifier indicates poor coagulation and/or poor handling of the formed floc. | ***Daily*** | Inspection should occur at different times of the day particularly during hot and or windy weather. |
| 10.10 | For sludge blanket clarifiers, the sludge blanket is monitored with online instrumentation. | A low or poor sludge blanket can indicate excessive sludge removal or polymer dosing. | ***Biennially*** | |

# Media Filtration

## Introduction

Secondary solids and pathogen removal step. In combination with optimised coagulation, flocculation and clarification, it is the main barrier to protozoan pathogens.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 11.1 | Filter operations have been optimised and consistently operated to achieve filtered water turbidity in line with Health Based Targets (WSAA 2014). | Maximum removal of pathogens requires the lowest possible filtered water turbidity. The available evidence is that pathogen removal is decreased if the filtered water is greater than 0.2 NTU (Xagoraraki et al (2004). | ***Continuously*** | The actual target values for LRV and therefore for post filter turbidity will depend on the source water assessment (WSAA 2014).<br>Log removal values of *Cryptosporidium* using conventional treatment are outlined below. Corresponding LRVs that can be claimed by Direct Filtration are in brackets.<br>4.0 log (3.5 log) removal requires:<br>Individual filter turbidity ≤0.15 NTU for 95% of the month and not >0.3 NTU for ≥15 consecutive minutes.<br>3.5 log (3.0 log) removal requires:<br>Individual filter turbidity ≤ 0.2 NTU for 95% of the month and not > 0.5 NTU for ≥15 consecutive minutes.<br>3.0 log (2.5 log) removal requires:<br>Individual filter turbidity ≤ 0.3 NTU for 95% of the month and not > 0.5 NTU for ≥15 consecutive minutes<br>(WSAA 2014)<br>Data should be based on a sampling interval for filtered water turbidity of ≤ 1 minute. (Ministry of Health NZ, 2018)<br>Data should include values from the ripening period and plant or filter start up unless filter to waste is present and operated for the full duration of the ripening period and start-up period.<br>Suitable alarms and CCPs are based around these turbidity limits to achieve log removals. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 11.2 | Approved (USEPA 180.1 or ISO 7027) turbidimeters are provided for each filter (Mosse et al. 2009; AwwaRF 2002; AWWA 2001) and operated according to manufacturer's specifications. | Allows assessment of individual filter performance and detection of poorly performing filters.<br>ADWG recommends individual turbidity meters on individual filters. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 11.3 | The design filtration rate is known, and the plant operates within the design specifications. | Exceeding the design specifications is likely to result in poorer performance of the process element and consequently poorer pathogen removal. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | The filtration rate could be calculated continuously and alarmed in the SCADA system. |
| 11.4 | Backwashes are triggered automatically by turbidity, head loss and run time (Kawamura 2000). | All three triggers are *enabled* at all times to provide adequate protection against the passage of pathogens. | ***Monthly*** | Triggers must not be turned off for "convenience". |
| 11.5 | In plants without filter to waste, the ripening period after backwashing does not exceed the turbidity target for any longer than:<br>0.5 NTU 15 min (3 log credit)<br>0.5 NTU 15 min (3.5 log credit)<br>0.3 NTU 15 min (4 log credit)<br>(WSAA 2014) | Any increase in turbidity represents increased risk to consumers. The ripening period is generally associated with a lower log removal (LRV) of pathogens.<br>The ripening period is defined as the time from the start of the filter run after backwashing until the target turbidity is consistently achieved. | ***Monthly*** | Turbidity alarms should be set on filtrate turbidity according to guideline numbers. |
| 11.6 | During backwashing and drain down, any increase in flow to those filters remaining on-line during the backwash is <20%. | Removal of a filter for backwashing without a reduction in plant flow results in sudden increases in flow rate through the remaining filters, resulting in shearing of floc and possibly the passage of pathogens through the filter. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | At least 6 filters are required without downrating flowrate during backwashing. |
| 11.7 | Media depths in all filters are within specifications. | Loss of media in any filter increases the risk of turbidity and pathogen breakthrough and may indicate chronic filter failure. Chronic filter failures have been identified as contributing to waterborne illness events. | ***Quarterly*** | The depth to the top of the media can be measured from a fixed reference point or alternatively, the media depth can be assessed based on lines painted on the walls of the filter indicating the specified bed depth. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 11.8 | Once triggered for backwash, the filter is shut down automatically and placed in a backwash queue. | Any filter showing turbidity breakthrough must not be allowed to continue filtering. Log removal (LRV) of pathogens at this stage is very low. | ***Biennially***<br>And after any major refurbishment, capital works or PLC modifications. | |
| 11.9 | Backwashing of dual media filters achieves >15% expansion of the filter coal, and > 95 % fluidisation of the filter media depth (sand and coal). (AwwaRF 2002, AWWA 2001)<br>Backwashing of monomedia sand filters achieves > 7% expansion and >20% fluidisation of the bed and/or combined air/water washing is employed. | Poorly backwashed filters result in reduced plant capacity and pathogen removal. | ***Quarterly*** | Typically filter coal bed expansion is up to 25 %.<br>Methods for measurement of fluidisation and expansion can be found in Mosse and Murray (2009). |
| 11.10 | The backwash rate should be controlled so as to minimise the risk of filter bed disturbance. | Backwashing can disturb the gravel layers that support the filter media especially if the rate is variable. | ***Biennially***<br>And after any major refurbishment, capital works or PLC modifications. | Where backwash water is provided from a backwash tank via a rate control valve it is common to find disturbed gravel layers due to flow variations via the rate control valve. |
| 11.11 | Air should be released from the underdrains smoothly following air scour. | Trapped air in the backwash piping can be released in an uncontrolled manner. | ***Biennially***<br>And after any major refurbishment, capital works or PLC modifications. | An air release valve or gradual increase in backwash rate can assist in removing the air smoothly. |
| 11.12 | Combined air scour low rate wash if present is < 15 m/h. | The combination of high rate water wash and air scour can result in damage to the filter under drain systems and displacement of the support gravels. | ***Annually***<br>And after any major refurbishment, capital works or PLC modifications. | |
| 11.13 | A full filter inspection (including, where relevant, the plenum space) is carried out regularly (Kawamura 2000) or after significant dirty water events. | Filter media and underdrains can deteriorate significantly and compromise filter performance. | ***Annually*** | Details of a full filter inspection can be found in Mosse and Murray (2009). |
| 11.14 | The rate of headloss increase should remain linear for a fixed flow rate. Any tendency for a curved rate of increase suggests problems with the filter. | Curved headloss trends suggest surface blinding of the media often resulting from overdosing of polymer. | ***Monthly*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 11.15 | Continuous recording and display of turbidity, filter flow, head loss and filter level or filter outlet valve position, is provided on the plant SCADA. | Filter performance trends are essential for filter optimisation and problem diagnosis. | ***Daily*** review of trends.<br>***Annually*** review of SCADA set up. | |
| 11.16 | Air scouring is practised where polymer is employed in the treatment process. | Polymer residual can carry over to filters and bind filter media. Air scouring is necessary to break the bonds between the floc polymer and the media. | ***Biennially***<br>And after any major refurbishment, capital works or PLC modifications. | Air scouring may also be required in some plants not using polymer, e.g. Iron (Fe) and Manganese (Mn) removal plants.<br>Air scour duration should be at least 120 s for plants using a coagulant and an organic polymer for coagulation, flocculation or filtration aid. Air scour should be at least 60 s for plants using inorganic coagulants alone. |
| 11.17 | Clean bed head loss (CBHL) is monitored during operation and long-term trends assessed and reported. | Any sustained increase in CBHL indicates fouling of the media and possible poor log removal efficiency. | ***Monthly*** | For a given filter flow rate, the clean bed head loss (after backwash) should remain within a target of 5% of the original CBHL. |
| 11.18 | Flow through the online turbidimeters is within the manufacturer's recommended ranges and is checked regularly. | Low or inconsistent flows compromise the quality of key monitoring data. | ***Daily*** | Simple observation of flow from the discharge during a daily plant inspection walk will suffice.<br>An air gap in the plumbing of the discharge line makes observation simple. |
| 11.19 | Where filter to waste is provided, it should have the capacity to accept the full filter flow and the waste period is adjusted to remove as much of the ripening peak as possible (AwwaRF 2002). | Water produced during the ripening period has a higher turbidity and lower pathogen removal. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 11.20 | Individual filter flow is monitored and trended (AwwaRF 2002). | Monitoring is necessary to ensure equal flows and loads to each filter. Unequal flows can result in differential performance of filters. | ***Continuously*** | |
| 11.21 | Filters are drained (or in the case of pressure filters, drained and opened) and a surface inspection is carried out (AwwaRF 2002). | Filter media can deteriorate significantly and relatively rapidly resulting in compromised filter performance. | ***Quarterly***<br>And after a significant dirty water event. | Note that inspection of the surface does not require entry into the filter. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 11.22 | Backwash time is set based on the backwash water at the end of the backwash having a turbidity of 10-15 NTU (Kawamura 2000). | Over-backwashing of filters can result in lengthy ripening of the filter and thus an increased risk of the passage of pathogens (reduced LRV). | ***Quarterly***<br>And after a significant dirty water event. | Backwash time required will also change based on water temperature. |
| 11.23 | Backwash rates are modified for water temperature. | A higher backwash rate will be required to achieve the same bed expansion in warmer water temperature. | ***Quarterly*** | Water temperature should be monitored continuously. |
| 11.24 | A backwash is observed on each filter regularly. | Without careful observation, backwash deterioration will not be detected. | ***Monthly*** | Filters can deteriorate rapidly and result in expensive rehabilitation works if problems are not identified and corrected early.<br>Photographs or videos of a backwash can be useful evidence when investigating filter issues. |
| 11.25 | Filter media is topped up when media loss exceeds 20 % of the original depth (Kawamura, 2000) | Filter media loss leads to higher pathogen breakthrough risk. | ***Quarterly***<br>Check of media depth. | Before topping up, the filter needs to be backwashed repeatedly and any mud completely removed. The new media should have the same specifications as the media that is in the filter. |
| 11.26 | Backwash rates are set based on the actual media specifications. | Density of filter media can vary especially between Australian filter coal and US anthracite. The manufacturer should provide backwash curves to establish appropriate backwash rates. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 11.27 | Where particle counts are used, the target for particles in the size range 2- 15µm is <20/mL, with a critical limit of<br><100/mL (Murray et al. 1999). | Particle counting is considered to be a more sensitive measure of filter performance, and therefore whether pathogen breakthrough may have occurred. | ***As required***<br>Usually project based. | Particle count checks are recommended for a treatment plant treating high risk water. |

# Membrane Filtration

## Introduction

Membranes provide a primary or secondary solids and pathogen removal step. A significant barrier to pathogens, superior to granular media filtration in this regard. Performance dependent on nominal pore size and membrane type.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 12.1 | Individual train filtered water turbidity target of <0.1 NTU and critical limit of not >0.15 NTU for ≥ 15 consecutive minutes applies, but preferably < 5 minutes. | Maximum removal of pathogens requires the lowest possible filtered water turbidity. | ***Continuously*** | |
| 12.2 | Pressure decay testing (PDT) for direct membrane integrity assessment is carried out regularly. Membrane fibres are repaired immediately if a PDT fails and a PDT is then repeated. | Individual membrane fibres can rupture or block and need to be pinned. Sonic testing identifies which modules may be breached.<br><br>A PDT target should be set based on membrane design and manufacturer specifications. | ***Daily (or 24 hr run time)***<br><br>**Event Based** | Failure on turbidity should also trigger a PDT |
| 12.3 | Trans-membrane pressure (TMP) is monitored during operation. | Excessive trans-membrane pressure indicates fouling and a need for backwashing or chemical cleaning.<br><br>A decrease in trans-membrane pressure indicates a loss of membrane integrity. | ***Monthly*** | A decrease in TMP requires inspection to identify the module with a problem. This module should be isolated until remedial action can be taken. |
| 12.4 | Post backwash TMP is within 20 % of the original TMP. | Any significant change in TMP can indicate blockages or ruptures of membrane fibres. | ***Monthly*** | |
| 12.5 | Backwashes are triggered automatically on time, resistance (TMP) and permeability. | Regular backwashes are required to protect membrane integrity and prevent turbidity breakthrough. | ***Monthly*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 12.6 | Membrane type and chemical cleaning systems are compatible. | Some membranes are very sensitive to different cleaning chemicals.<br><br>Cleaning chemicals should be compatible with the particular membrane type and should also address the contaminants to be removed. | ***Design Review***<br><br>***Biennially thereafter***<br><br>And after any major refurbishment or capital works. | Typically, acid cleaning is for inorganic deposits, alkali or surfactant for organics, and disinfectants or oxidants for biological fouling. |
| 12.7 | A full membrane system inspection is carried out at least once per year (Kawamura 2000). | Membranes can deteriorate significantly without adequate maintenance and checking. Checks can include measuring membrane module diameters for evidence of swelling or weighing modules for assessing solids accumulation. | ***Annually*** | Periodic membrane autopsies may also be carried out to check for contamination of the membrane material. |
| 12.8 | The design flux rate ($L/m^2/h$) is known and the plant operates within the design values. | Exceeding the design specifications may result in reduced log removal of pathogens. | ***Quarterly*** | The flux is the amount of permeate produced per unit area of membrane surface per unit time and is usually expressed as $L/m^2/h$. |
| 12.9 | Approved (USEPA 180.1 or ISO 7027) turbidimeters are provided and installed and operated according to the manufacturer's specifications. | Allows assessment of membrane performance and detection of poorly performing modules. | ***Design Review***<br><br>***Biennially thereafter***<br><br>And after any major refurbishment or capital works. | |
| 12.10 | Continuous display and recording of online turbidity, filter flow, transmembrane pressure and pressure decay testing is provided. | SCADA trends are essential for optimisation and problem diagnosis. | ***Biennially***<br><br>***Weekly*** review of data. | |
| 12.11 | Normalised water permeability (NWP) ($L/m^2$-h-bar) is determined under standard pressure and temperature conditions. | The NWP values are compared to initial levels trended over time as an indication of the health and cleanliness of the membrane. | ***Monthly*** | NWP =<br><br>Total permeate flow/total membrane area<br><br>TMP<br><br>The measured NWP should be within 20% of the membranes design NWP. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 12.12 | The cleaning regime for the membranes is regularly reviewed and optimised. | The frequency of normal backwashes and chemical cleans should be regularly checked and optimised. | ***Quarterly*** | Membrane permeability and transmembrane pressure should be reviewed before and after cleaning. |
| 12.13 | Flow through the turbidimeters is within the manufacturer's recommended ranges and is checked regularly. | Low or inconsistent flows compromise quality of process monitoring data. | ***Daily*** | Simple observation of flow from the discharge during a daily plant inspection walk will suffice.<br>Introduction of an air gap in the discharge line makes assessment of flow through the meter easily observed. |
| 12.14 | Pre-membrane treatment is provided for all anticipated contaminants. | Damage, blocking or contamination of the membranes can lead to reduced performance and shortened life. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Membranes can be damaged by grit.<br>Pores may be blocked by high solids loads. Inorganic fouling (dissolved metals and mineral salts, in particular Fe and Mn) or organic fouling (dissolved organic carbon, particularly the hydrophobic fraction or dosed polymer) may occur with molecules adsorbing to the membrane surface. |
| 12.15 | Feed water temperature is monitored continuously during operation. | Flux at a given TMP is strongly affected by feed water temperature due to the changes in the viscosity of the water. Flow rate may need to be decreased at lower temperatures. | ***Monthly*** | |
| 12.16 | Membrane age, life expectancy and repairs should be tracked. | Records should be kept on the number of fibres repaired in each module including type of failure (e.g. break, pin hole, slit) | ***Quarterly*** | |
| 12.17 | Particle counts in the size range 2-15μm <20/mL and a critical limit <100/mL (Murray et al 1999). | Particle counting is a more sensitive measure of particles and therefore pathogen breakthrough. | ***Biennially*** | |

# GAC/ BAC Filters

## Introduction

GAC or BAC filters are often a secondary filtration process that provides an additional barrier for the removal of organic compounds.

While this section does not relate specifically to management of microbial risk it is included for completeness.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 13.1 | Empty bed contact time (EBCT) is at least 7 min, but preferably 10 min or more. | Sufficient EBCT is required for adsorption of organics to occur effectively throughout the filter media. | ***Annually*** | The EBCT should be sufficient to allow removal of the target contaminant.<br>This can be best established using pilot plant and laboratory trials. |
| 13.2 | The design filtration rate is known, and the plant operates within the design specifications. | Exceeding the design specifications is likely to result in poorer performance of the process element and consequently poorer removal of the contaminant. | ***Annually*** | The filtration rate can be calculated continuously and alarmed in the SCADA system. |
| 13.3 | Surface loading rate is between 5 to 15 m/h | Necessary to ensure effective contact. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 13.4 | Backwashes are triggered automatically by run time. | Typically, every 1 to 5 days | ***Annually*** | Check that turbidity and headloss are satisfactory during runs |
| 13.5 | Backwash incorporates air scour and water wash and preferably a combined air/water wash step. | Air scour is critical to break up bacterial build up that can cause carbon particles to clump together. Water washing alone may not effectively clean a BAC filter. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 13.6 | The carbon bed depth is monitored and within specification. | Loss of media in any filter decreases performance. | ***Quarterly*** | The depth to the top of the media can be measured from a fixed reference point or alternatively, the media depth can be assessed based on lines painted on the walls of the filter indicating the specified bed depth. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 13.7 | Backwashing of the filter achieves bed expansion at least 25 %, preferably 30% | | ***Quarterly*** | |
| 13.8 | Filters that have been taken off line for an extended period should be backwashed. | Biological material may stream from the filter when restarted if it had been sitting off-line for some time prior. The pH may also have dropped in the filter. | ***Monthly*** | |
| 13.9 | The backwash rate is controlled and the rate of change managed to minimise bed disturbance. | A gradual increase in backwash rate will allow for bed expansion from the top downward. Otherwise the bed can rise as a plug especially if backwashing has not been conducted regularly.<br>Gradual reduction of the backwash rate at the end of a backwash cycle, allows for restratification. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Activated carbon beds can be sensitive to backwash rate especially if there has been a significant build-up of biota since the last backwash. |
| 13.10 | Backwash rates are set based on the actual media specifications and water temperature. | Density of GAC can vary among different carbon brands. The manufacturer should provide backwash curves to establish appropriate backwash rates. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 13.11 | Monitoring protocols are established for dissolved oxygen (DO) and t pH of the influent and effluent of each BAC filter. | Changes in DO and pH should be regularly monitored through each BAC filter to examine<br>degree of biological activity in the BAC column. Abnormal activity should be further investigated. | ***Investigate abnormal results*** | Sampling from the BAC filters waste wash water for biomass concentration may also assist. |
| 13.12 | The Iodine number is measured periodically and the GAC is replaced when the Iodine number, goes below 500 mg/g carbon (AWWA, 2005) | A decrease in Iodine number to below 500 mg/g indicates that the adsorptive capacity of the GAC has diminished and requires replacement to increase removal efficiencies. | ***Annually***<br>And before summer or when increased organic loads are expected. | The iodine number is the mass of iodine absorbed from 1g of carbon, the iodine number decreases with time as available adsorption sites are filled. |

# Ozonation

## Introduction

Ozone reacts with natural organics to produce lower molecular weight compounds that are more biodegradable and promote growth of bacteria, which is taken advantage of in biological filtration. While ozone can be used as a disinfectant, this is not common in Australia. Therefore while this section does not relate specifically to management of microbial risk it is included for completeness.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 14.1 | Ozone effective contact time is at least 5 minutes and preferably 10 minutes. | Ozone requires at least 5 minutes for oxidation and longer for adequate disinfection. Contact time should also be limited in order to minimize DBP formation. (Kawamura, 2000) | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | The system should be designed for minimum contact time at the maximum flow rate |
| 14.2 | The pH of ozonation is optimised between 6.5 and 8 | Ozonation is most stable in this range. | ***Continuously*** | Bromate formation is reduced in the lower end of the pH range |
| 14.3 | Turbidity is less than 1 NTU at the point of ozone application. | Ozone is highly sensitive to turbidity and increased turbidity can lead to ineffective ozonation. | ***Continuously*** | |
| 14.4 | A well-designed mixing system (static or mechanical) or contactor is provided to allow for transfer of ozone to water. | Mixing ensures even contact and dispersion of ozone and minimizes DBP (primarily bromates) formation.<br>Ozone has low solubility in water, so effective mixing and contact time are important | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 14.5 | There is an effective gas destruction system for off-gas that results during mixing. | Ozone contact typically has up to 95% transfer of ozone to the water. The remaining percentage results as off-gas. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 14.6 | Bromide in the raw water is monitored. | Bromide can be converted to bromate which has a health limit in ADWG of 0.02 mg/L | ***Monthly*** | Monitoring of bromate is recommended if the bromide concentration in the raw water is greater than 0.20mg/L. |
| 14.7 | Ambient ozone is measured continuously. | Ozone is a toxic gas and the facilities should be designed to control this gas to protect plant personnel. | **Continuously** | |

# Chlorine-Based Primary Disinfection

## Introduction

Chlorine-based disinfection (free chlorine or chloramine) is an effective barrier for bacteria and most viruses; however, at the concentrations typically used in a conventional water treatment plant, it is not an effective barrier for protozoan pathogens.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| | CHLORINATION AND CHLORAMINATION | | | |
| 15.1 | Primary disinfection is based on achieving a minimum target Ct for the water temperature and pH at all times. | Control of pathogens using chlorine-based disinfectants is determined by a C*t* value to ensure adequate disinfection based on both adequate disinfectant residual and contact time. | ***Continuously*** | The disinfectant residual is dependent on temperature and should be corrected for pH. The necessary contact time can be determined by:<br>• a baffling factor (see Appendix 1<br>• tracer studies ($T_{10}$t) or<br>• computational flow dynamics. |
| 15.2 | There is a system in place to ensure that no undisinfected water leaves the water treatment plant. | Distribution of water that has not been disinfected for the target C*t* should never occur. | ***Continuously*** | Online monitoring and a PLC interlock with the treated water pump(s) is essential to ensure this. |
| 15.3 | Short circuiting is minimised in the contact tank and in treated water storages. | Short circuiting compromises achievement of C*t*. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 15.4 | Data collected to calculate Ct should be based on a sampling interval of ≤1 min. | Small sampling intervals ensure Ct is being met at all times. | ***Continuously*** | Ct should be calculated based on chlorine residual at the end of the contact time. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| | **CHLORINATION** | | | |
| 15.5 | Free chlorine residual is monitored downstream of the primary dosing point after it is well mixed using online instruments. | Well maintained online instruments are essential to ensure continuous disinfection is achieved. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Chlorine residual should be monitored between 2 and 10 minutes after dosing with feedback control of primary dose. It should also be monitored at the end of chlorine contact time for additional control and management of the chlorine residual. |
| 15.6 | Chlorine dosing is flow paced and residual trimmed. | The dosing system needs to provide constant feedback control to maintain a setpoint residual regardless of flow changes and chlorine concentration, particularly changes in concentration caused by the decay of stock solutions of sodium hypochlorite. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 15.7 | pH is monitored online at the point where online monitoring of chlorine residual occurs. | Measured pH allows calculation of FACE (free available chlorine equivalent) which is the free chlorine concentration corrected for pH. This is necessary since free chlorine is less effective at higher pHs. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| | **CHLORAMINATION** | | | |
| 15.8 | Online monitoring for chloraminated systems includes total chlorine and monochloramine concentration. | Well maintained online instruments are essential to ensure continuous disinfection is achieved. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 15.9 | Initial dosing of chlorine and ammonia is set to achieve at least 90% of the total chlorine as monochloramine. | In operating chloraminated systems it is important to manage the chlorine to ammonia ratio to maximise production of monochloramine while minimising free ammonia and production of di and tri chloramine. | ***Weekly*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 15.10 | Initial dosing of chlorine and ammonia is set to achieve a free ammonia <0.2 mg/L 90% of time. | High free ammonia encourages nitrifying bacteria to become established. | ***Weekly*** | Free ammonia <0.1 mg/L is better still and further limits nitrification but can be difficult to achieve in some systems. (Mosse, Braden and Hourigan, 2009). |
| 15.11 | The chlorine to ammonia ratio is determined and recorded weekly. | The chlorine to ammonia ratio is critical to achieving formation of monochloramine while limiting the amount of free ammonia remaining and the production of di- and tri-chloramine. | ***Weekly*** | The chlorine to ammonia ratio is typically between 3.5:1 and 4.5:1 (Mosse, Braden and Hourigan, 2009).<br>The necessary ratio can vary and is affected by the pH and temperature. |
| 15.12 | Free ammonia, nitrite and nitrate are monitored at the dosing point and at multiple sites in the distribution system. | Within one to two weeks of the onset of nitrification, chloramine residuals can decrease rapidly. The levels of free ammonia typically decrease, while nitrite and nitrate increase shortly before this occurs. | ***Weekly***<br>The frequency can be decreased during periods when nitrification is less likely. | The frequency of monitoring should be increased during periods of high temperatures, low pH or long detention times.<br>Nitrite and nitrate should be maintained at the lowest possible levels. Any sudden increase indicates the onset of nitrification. |
| 15.13 | Optimum or near optimum pH is maintained for monochloramine stability. | The target range for pH during chloramination is usually 8.5 ± 0.2. Monochloramine stability improves with increased pH. | | However, this should be balanced with a target pH range of 6.5-8.5 for final water. |
| 15.14 | pH, temperature and DOC) are monitored regularly. | Low pH, warmer temperatures (>15$^{O}$C) and increases in DOC can lead to loss of residual and nitrification. | ***Weekly*** | |

# UV Disinfection

## Introduction

UV disinfection provides an additional barrier in high risk locations for removal of viruses, protozoa and bacteria, if the UV Reduction Equivalent Dose is sufficient.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 16.1 | The UV equipment has been validated and is able to achieve a minimum UV Reduction Equivalent Dose (RED) (mJ/cm$^2$). | Validated systems have been proven to achieve the necessary conditions to control pathogens. Other systems may not. | ***Design Review*** ***Biennially thereafter*** And after any major refurbishment or capital works. | The system should have alarms and automatic shutdown in place if minimum UV dose is not being achieved, this includes the period where the lamps are warming up |
| 16.2 | The UV system operates at ≥ design UV transmittance (UVT - %). | Operation outside the design specifications will not result in the required log removal of pathogens. | ***Continuously or Daily*** | Online transmissivity monitoring is preferred but at least a portable transmissivity meter should be provided. |
| 16.3 | The UV system operates within design specifications for UV intensity and/ or UV dose. | Operation outside the design specifications will not result in the required log removal of pathogens. | ***Monthly*** | Most UV systems include UV intensity monitoring which should alarm when below set levels. |
| 16.4 | The UV system operates within design specifications for flowrate. | UV systems are validated in terms of minimum and maximum flow rates (L/s). | ***Continuously*** | |
| 16.5 | The UV lamp run time is monitored and tracked against lamp expiry age | Validated UV lamp performance is not guaranteed by a manufacturer after lamp expiry date. | ***Monthly*** | |
| 16.6 | Regular servicing/calibration by a specialist is undertaken. | Regular servicing maintains the systems efficacy and validation. | ***As specified by the manufacturer*** | Maintenance should include calibration, verification and replacement (if required) of intensity sensors, lamps, quartz sleeves and intensity sensor windows. |
| 16.7 | Regular manual cleaning of the lamps and quartz sleeves is undertaken | Manual cleaning can remove deposits and prevent fouling of the lamps | ***As specified by the manufacturer*** | |

# Equipment and Instrumentation

## Introduction

Equipment and instrumentation is essential for operation of a water treatment plant.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 17.1 | Online instruments are positioned as close as possible to the point of sampling and the time for the sample to reach the analyser is known. Sampling should be from the middle of the pipe in most cases. | Long sampling lines introduce delays that make PLC control difficult. The lines may also become fouled and lead to poor monitoring data. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | The diameter and length of the sample line should be minimised to avoid settling and reduce delays in feedback control loops. |
| 17.2 | All online and portable instruments are calibrated according to the manufacturer's recommendations. | Accurate and precise data is essential for informing operational decisions and demonstrating performance. Regular calibration is necessary to achieve this. | ***As specified by the manufacturer*** | |
| 17.3 | Online turbidity meters (complying with USEPA 180.1 or ISO 7027) are provided for raw water monitoring. | Continuous monitoring of raw water turbidity provides early warning of the need to take urgent action to ensure continued optimised operation of a treatment plant. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 17.4 | Online pH meters are provided for raw water monitoring. | Changes in raw water pH due to seasonal changes or to algae in the water can impact adversely on coagulation and therefore pathogen removal. With algae, the pH may change during the day, being higher during the day and lower at night. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 17.5 | Raw water flow meters are provided at the inlet to the plant. | Reliable measurement of plant flow is essential for flow paced dosing of all chemicals and ensuring that any flow rate changes occur at a slow enough rate. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 17.6 | There is online monitoring of coagulation pH. | Optimised coagulation, which is pH sensitive, is essential for maximum pathogen removal.<br>This is particularly important for alum. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 17.7 | Online instrumentation is installed according to the manufacturer's specifications. | Many online instruments are located outside and exposed to the elements. Manufacturers often specify acceptable temperature ranges for operation. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | Particular attention needs to be given to maintaining the ambient temperature within the range specified and maintaining the required flow rate through the instrument where relevant. |
| 17.8 | Sufficient laboratory equipment and stock jar testing chemicals are available to allow for the performance of a jar test at any time. Minimum equipment includes:<br>• Calibrated portable pH meter<br>• Calibrated portable turbidity meter able to measure accurately below 1 NTU with 0.1 NTU accuracy<br>• Operational jar test machine and matched "jars".<br>• Syringes or adjustable micropipettes. | An operator needs to be able to respond rapidly to changes in source water quality and establish the optimum coagulation requirements. | ***Annually*** | |
| 17.9 | A functioning portable chlorine meter is available. | Regular checking of chlorine residuals is a key component for ensuring adequate disinfection. | ***Annually*** | |
| 17.10 | Critical alarms are notified to operational staff 24/7 with appropriate escalation if the alarm is not acknowledged. | Critical alarms must be responded to as quickly as possible. In the event that the primary contact does not acknowledge an alarm, an alternative staff member must be notified. | ***Annually*** | A recommended check is to adjust the critical parameter so that it is out of range and the full alarm response then monitored. The primary contact should be instructed not to respond to check the escalation occurs as planned. |
| 17.11 | Differential pressure/head loss gauges are provided on individual filters. | Monitoring head loss accumulation during a filter run enables the media loading characteristics to be observed and provides some assessment of the effectiveness of backwashing. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 17.12 | Access to qualified and skilled instrument and SCADA technicians is formalised. | Ongoing reliable operation of water supply systems requires routine maintenance, and timely breakdown repair services. | ***Biennially*** | |
| 17.13 | Laboratory glassware, reagents and in date consumables are provided for jar testing and laboratory process monitoring. | Dirty glassware, out of date reagents, reused syringes and sample bottles can all lead to false results and misinformation for operational decision making. | ***Annually*** | |
| 17.14 | Sufficient spares are maintained for critical monitoring equipment to ensure continuity of monitoring. | Reliable continual monitoring of critical parameters is essential to minimise development of incidents and demonstrate full compliance with targets. | ***Annually*** | |
| 17.15 | Where treatment processes have parallel trains, controllers and/or analysers that have the capacity to shut down the WTP should be installed on each train. | Having multiple analysers for multiple process trains minimises the risk of treatment failure in the event of controller/analyser failure. | ***Annually*** | |
| 17.16 | Critical instruments are configured to provide an alarm on SCADA if there is an instrument fault. | The failure of critical instruments needs to be dealt with quickly in order to maintain a satisfactory treatment system. | ***Annually*** | |
| 17.17 | Instruments are calibrated and serviced regularly | Necessary to ensure accurate data | ***As specified by the manufacturer*** | |
| 17.18 | Online and handheld analysers should measure parameters using the same methodology and test for parameters in the same units. | To ensure consistent results | ***Biennially*** | Different methods of testing for turbidity are available e.g. USEPA or ISO. For comparable results, all analysers should use the same method. |
| 17.19 | Emergency power supply is provided for sample pumps and online analysers associated with critical processes. | In the event of power failure some critical information may still be required | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |

# Distribution System

## Introduction

Safe drinking water must be maintained throughout the distribution system through the provision of an adequate disinfection residual and system integrity. There is limited ability to reduce the levels of pathogens, particularly protozoan pathogens in a distribution system, therefore recontamination must be prevented.

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.1 | In chlorinated systems, a free chlorine residual is always maintained in all treated water storages. | Treated water storages have regularly been identified as sources of contamination. | ***Continuously*** | The actual free chlorine level necessary depends on the detention time in the storage and what is necessary to achieve 0.2 mg/L at the ends of the distribution system (see below).<br>The necessary concentration may also vary with water temperature. |
| 18.2 | In chlorinated systems, a free chlorine residual (free available chlorine equivalent (FACE) corrected for pH) of ≥0.2 mg/L is consistently maintained at the ends of the distribution system at all times (Mosse & Deere 2009; NZ MoH 2008). | Free chlorine residual in the water provides some protection in the case of minor contamination events where bacteria may enter the system.<br>It also assists in the management of biofilms and limiting regrowth of opportunistic pathogens.<br>Higher levels may be necessary for control of specific microbes e.g.<br>*Aeromonas* or *Naegleria.* | ***Weekly*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.3 | All treated water storages have:<br>• Fully intact roofs that do not allow any runoff to enter the storage.<br>• Walls and screening to prevent access of vermin or ingress of water contaminated with faecal material.<br>• Any gutters must be designed to prevent ingress of water from the gutter.<br>• Screened overflow pipes. | Treated water storages have regularly and repeatedly been identified as sources of contamination. | ***Quarterly*** | Poorly maintained roofs allow contaminants to enter the storages.<br>Whirly birds and other ventilation structures must also be installed to prevent access to the storage by vermin.<br>Screen mesh size should be such that all vertebrate organisms are excluded.'<br>A preferable alternative to gutters is to allow water to run freely off the roof to be collected and managed by the stormwater collection on the ground. |
| 18.4 | The integrity of treated water storages is regularly assessed and recorded. The interval is dependent on the risk profile, age, design and material quality of the storage. | Treated water storages have been regularly and repeatedly identified as sources of contamination.<br>Older storages and poor-quality storages require more frequent inspection.<br>While drone inspections are practical, they should be supplemented with full human visual inspections. | The assessment interval varies:<br>• **Monthly** for a storage in poor condition<br>• **Quarterly** for storages in reasonable condition<br>• **Annually** for new, well designed storages.<br>Each Utility must determine a frequency based on their assessment of the risk posed by each storage. | After any water quality event linked to the storages, the integrity of all storages needs to be carefully assessed.<br>Internal assessment of the integrity can be undertaken whenever maintenance activities are implemented including diver cleaning of storages.<br>Buckets tests or flood tests can be used to check the integrity of a storages roof structure. This should ideally occur when a tank has been drained and prior to it being cleaned. |
| 18.5 | In chloraminated systems, the total chlorine residual at the ends of the distribution system is consistently maintained >1.5 mg/L. (Mosse & Deere 2009, Chow et al 2014) | Experience in Australia has shown a sustained total chlorine residual above 1.5 mg/L at the ends of the distribution system minimises the risk of nitrification. | ***Weekly*** | |
| 18.6 | In chloraminated systems, the monochloramine residual throughout the distribution system is at least 1.5 – 2.5 mg/L. (Mosse & Deere 2009) | Experience in Australia has shown a sustained monochloramine residual above 1.5 mg/L throughout the distribution system minimises the risk of nitrification. | ***Weekly*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.7 | Backflow prevention devices (BFPDs) are in place and are relevant to the level of associated risk. | Backflow has been consistently identified as a cause of outbreaks of waterborne disease. | ***Design Review***<br>***Biennially thereafter***<br>And after any major refurbishment or capital works. | |
| 18.8 | High risk BFPDs are tested annually as per AS 2845 (Water supply backflow prevention devices). | Testable BFPDs are required where any backflow presents a high risk of contamination of the distribution system. | ***Annually*** | |
| 18.9 | There is a program to regularly check a proportion of domestic backflow prevention devices. | Backflow prevention devices can fail. | ***Annually***<br>The interval depends on the nature of the raw water. | The proportion tested depends on the rate of failure experienced in a given water supply. |
| 18.10 | In chloraminated systems, ammonia, nitrite and nitrate are measured frequently to provide an indication of the onset of nitrification. | The biggest risk with chloraminated systems is the onset of nitrification. | ***Weekly*** during critical periods of high temperatures, low pH or long detention times.<br>The interval can be decreased during periods when nitrification is less likely. | Nitrification is easier to control if it is detected early.<br>It is possible to recover from mild nitrification while it is very difficult to recover the system when severe nitrification occurs. |
| 18.11 | In chloraminated systems, the distribution system is operated to achieve the highest possible ratio of monochloramine to total chlorine throughout the system. | Low ratios of monochloramine: total chlorine in the distribution system indicates poor operation of the system.<br>Likely causes are dirty mains and long detention times with stagnant water. | ***Weekly*** | A recommended target is >90% monochloramine: total chlorine. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.12 | In chloraminated systems, the pH is maintained between 8.0 and 8.5. (Mosse & Deere 2009, Chow et al 2014) | pH <7.8 results in rapid decay of chloramine residuals and promotes nitrification. | ***Weekly*** | Continuous monitoring at key points in the distribution system is recommended.<br>Monochloramine stability improves at pH levels >8.5 however this is outside ADWG limits for pH. Monochloramine stability needs to be balanced against the ADWG target pH range. There may be some instances in which the relevant health regulator will approve the use of a higher pH. |
| 18.13 | There is a detailed procedure for the control of nitrification, including immediate actions once it is has been identified from monitoring. | Once nitrification has been identified, the most likely chances of success are if it is treated as soon as possible. | ***As required***<br>Event based | The most common method is to super chlorinate the system.<br>High levels (but below the ADWG health limit of 5 mg/L) for short periods are recommended to minimise consumer dissatisfaction. |
| 18.14 | Treated water storages are regularly cleaned of sediments. | Treated water storages have been regularly and repeatedly identified as sources of contamination. | ***Annually***<br>The necessary interval depends on the nature of the raw water and the control of coagulation at the treatment plant.<br>**Annual** cleaning is recommended as a minimum, but an alternative cleaning frequency may be used based on the development of a risk-based cleaning program. | Regular diver inspection can be used to help determine the cleaning interval. |
| 18.15 | Hygienic work practices are applied during work on the distribution system and particularly during mains repairs where dewatering of the main is required. | Failure of hygienic work practices during mains repairs can result in contamination of water supplied to consumers and illness (Nygard et al 2007). | ***Event Based***<br>Regular field audits should be carried out to confirm adherence to hygienic work practices. | Ideally this requires complete separation of sewer and water maintenance.<br>If this is not possible, full disinfection of all tools and equipment and workers' boots is required prior to working on drinking water supply systems.<br>Disposable overalls or a clean set of clothes should be worn by staff carrying out the repair. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.16 | After completion of a mains repair where a section of main was isolated and dewatered, the isolated section is flushed at a velocity of 1 m/s for at least 3 pipe volumes (AWWA (2105); Yang et al (2015); Water research Foundation (2014)). | Failure of hygienic work practices during mains repairs can result in contamination of water supplied to consumers and illness (Nygard et al 2007). | ***Event based*** | A free video demonstrating best practice mains repairs for the maintenance of safe drinking water is available on the WIOA website. |
| 18.17 | If during mains repair, contamination may have occurred by, for example, potentially contaminated soil or water entering the main, remedial action must be taken. | Any violation of the integrity of the distribution system represents a site for potential recontamination and must be managed according to the level of risk. | ***Event based*** | In the first instance, the potentially contaminated section of main should be flushed at a velocity of at least 1 m/s (i.e. 3 ft/s) for at least 3 pipe volumes.<br><br>This is followed by disinfection with a free chlorine Ct of 100 mg.min/L (AWWA (2015); Yang et al. (2015); Healy et al (2017))<br><br>If this cannot be achieved, or the contamination is severe enough, a boil water advisory should be implemented for all downstream properties until such time as the water can be verified as being safe to drink. |
| 18.18 | A Safe Water, Water Mains Repair Procedure is in place. | Failure of hygienic work practices during mains repairs can result in contamination of water supplied to consumers and illness (Nygard et al 2007). | ***Event based and Ongoing*** | A free video entitled Safe Water, Water Mains Repairs is available on the WIOA website.<br><br>Spot checks should occur to ensure all staff are following procedures in place. |
| 18.19 | Regular field audits are carried out to confirm adherence to hygienic work practices. | All work practices benefit from regular assessment and review. | ***Annually***<br><br>Audits should be arranged so that each work team is assessed annually. | Surprise audits and audits by external specialists are recommended. |
| 18.20 | Training on appropriate hygienic work practices is provided to subcontractors working in the distribution system. | Subcontractors from outside the water industry are mostly unaware of the risks to public health of work carried out in the distribution system. | ***As required*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.21 | No actual or potential cross connections exist. | Actual cross connections have been identified in a number of third pipe reuse schemes and in systems where bulk raw water is supplied to some consumers as well as potable water.<br><br>Such cross connections have been consistently identified as a cause of waterborne disease. | ***Biennially*** | Many old towns and cities have old pipework that predates a treatment plant, occasionally allowing raw water bypasses around the plant.<br><br>Potential cross connections include water mains running in the same trenches as sewer mains.<br><br>Decommissioned treatment plants and distribution system assets, including storages, which have not been physically separated from the operational assets, are also a potential source of contamination. |
| 18.22 | A mains cleaning program is in place for the complete distribution system and appropriate testing such as ATP or HPC used to monitor and record the effectiveness of the cleaning. | Many problems with drinking water quality and safety of the water originate from dirty mains. | ***Based on monitoring data***<br><br>The interval should be determined by monitoring of key water quality parameters and indicators of condition of the inside of the pipes. | Reactive or part cleaning is generally not effective as a control measure. |
| 18.23 | A critical limit for Heterotrophic Plate Counts (HPC 22$^{O}$C) of <500 counts/mL as a 95$^{th}$ percentile is applied in the distribution system (Mosse & Deere 2009; USEPA 2006; Mays 1999). | HPC provide a measure of the cleanliness of the distribution system and can be a useful trigger for distribution system cleaning.<br><br>Important also in minimising taste and odour and dirty water complaints. | ***Monthly*** | A more stringent target of 100 counts per mL can be used (Mosse & Deere 2009). |
| 18.24 | A target for Adenosine Triphosphate (ATP) of <10 pg/L is applied in the distribution system. | ATP levels provide a measure of cleanliness of the distribution system and can be a useful trigger for distribution system cleaning. | ***Monthly*** | ATP levels can also be used as a check along with turbidity and chlorine residual after a mains repair. |
| 18.25 | In chlorinated and chloraminated systems, the pipe surface should be monitored and kept clean of biofilm and sediments. | Biofilms will form on the surface of piping which will usually result in a faster consumption of chlorine residuals. (Chow et al. 2014) | ***As Required***<br><br>Removal of biofilms if chlorine levels at the ends of the distribution have are too low | Flushing at high velocities or ice pigging can aid in removing the biofilms and/or sediments. |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 18.26 | New mains are installed according to the requirements of the WSAA Water Supply Code of Australia. | New mains, fittings and work practices are a potential source of contamination. | ***As Required*** | |
| 18.27 | Air valves are situated so that they cannot become submerged. | Air valves are a potential source of contamination. | ***Biennially*** | |
| 18.28 | In chloraminated systems the free ammonia is maintained <0.2 mg/L and preferably <0.1mg/L throughout the reticulation. | Free ammonia promotes nitrification. | ***Weekly*** | |
| 18.29 | Critical valves have been identified and are regularly exercised. | Critical valves must be operable at all times particularly during incidents. | ***Annually*** | |

# Water Quality Information Management

## Introduction

Sustained optimised operation of a water supply system requires accurate and precise data. The data needs to be provided in a timely manner and analysed to detect any drift away from optimised operation, or the development of conditions that may potentially lead to incidents or emergencies

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 19.1 | Multi-tiered alarms with the capability to shut down the treatment plant are in place for all control points monitored by online instruments. | Out of specification water must never leave the treatment plant. | ***Annually*** | |
| 19.2 | Alarm limits in the PLC accurately reflect the targets, alert limits and critical limits defined in the Drinking Water Quality Management Plan. | Operation of a water supply system should reliably reflect the outcomes of the risk assessment process and the Drinking Water Quality Management Plan. | ***Annually*** | Meaningful risk management requires water supply system alarms to be fully consistent with Drinking Water Quality Management Plan targets and critical limits. |
| 19.3 | A backup copy of the current SCADA and PLC program is maintained. | It is essential that the PLC and SCADA system can be re-established quickly after any loss of function. | ***Annually***<br>And whenever any change is made to the control system. | A hard copy of all critical setpoints should also be maintained at the treatment plant or head office. |
| 19.4 | Access to change critical alarm limits is restricted to authorised officers. | To protect public health, critical alarm limits must not be altered without approval. | ***Annually*** | |
| 19.5 | Long term SCADA trends of critical water quality parameters (e.g. individual filter water turbidity and disinfection residuals) are based on sampling intervals of no longer than 1 min (NZ MoH 2008). | Continuous (and not based on change of value) sampling at appropriately short intervals is necessary to allow for the confident detection of developing problems. | ***Annually*** | SCADA systems need to be set up to allow easy extraction of meaningful data. |
| 19.6 | Critical alarms are physically tested using, where appropriate, out of specification water samples. For example water with turbidity or pH levels > critical limit for the control point. | An alarm test should involve the entire alarm sequence from detection of a parameter that is out of specification through to the human response that corrects the alarm condition rather than the more simple electronic tests. | ***Annually*** | |

| | Measure | Rationale | Assessment Interval | Additional Information |
|---|---|---|---|---|
| 19.7 | Statistical analysis of treatment plant unit process performance and distribution system performance relevant to pathogen management is provided to senior management at regular intervals (AwwaRF 2002; AWWA 2001). | Results are compiled, and report compliance with water supply system targets to senior management.<br>Only long term statistical data allows evaluation of barrier performance.<br>Reporting to senior management allows the focus to remain where appropriate. | ***Monthly*** | Information around water quality related incidents and near misses should be captured so that the learning can be used to avoid repeat instances and develop improvement plans.<br>Many software packages are now available. Utilities should very carefully check the capability of the packages before purchase.<br>Two, simple-to-use data analysis packages (WTAnalyser filter and WTAnalyser disinfection) are available free of charge on the WIOA website. The packages provide long term statistical analysis of filter and disinfection performance. |
| 19.8 | There is a fully developed Information Management System (IMS) in place for water quality parameters and the system is fully integrated with SCADA systems. | Efficient recording of both online and laboratory data is essential to allow timely evaluation of microbial risk in a modern water supply system. | ***Ongoing*** | Change management procedures should ensure all changes to an IMS are reviewed and risks are considered prior to implementation. |
| 19.9 | SCADA trend data and reports are analysed daily and actions initiated when necessary. | Sustained optimised system operation requires timely analysis of time series trends. | ***Daily*** | |
| 19.10 | Non-SCADA water quality monitoring data is trended and analysed regularly. | Sustained optimised plant operation requires timely analysis of all monitoring data. | ***Weekly*** | |

# Appendix 1. Calculation of $T_{10}$

The $T_{10}$ contact time is defined in the USEPA Guidance Manual for Disinfection Profiling and Benchmarking (2003) as the minimum detention time experienced by 90 percent of the water passing through the tank. It is the time it takes for the chemical tracer $C_{out}/C_{in}$ to reach 0.1 indicating that 90% of the rest of the water is still in the tank (see Figure 1).

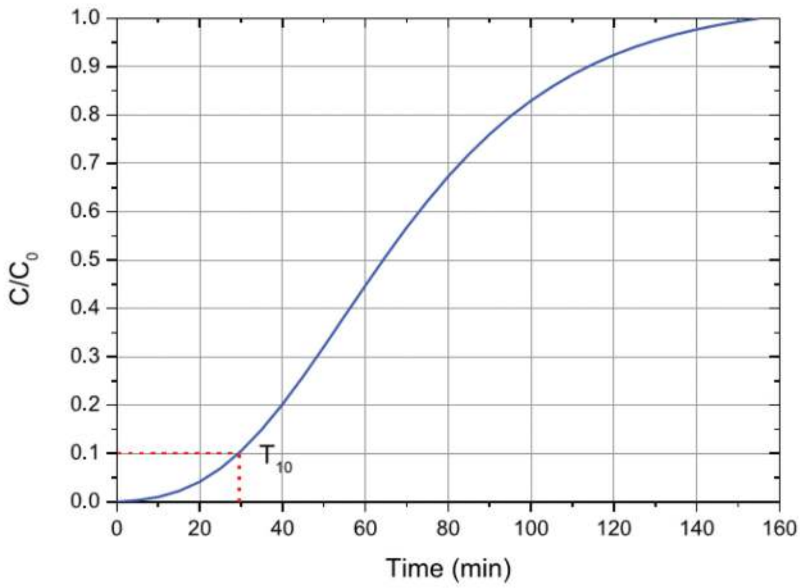


*Figure 1. Step dose tracer test – cumulative distribution curve (taken from USEPA Guidance Manual for Disinfection Profiling and Benchmarking, 2003)*

While actual tests like that shown in Figure 1 can be conducted, the $T_{10}$ can be *estimated* by using a baffle factor (Table 1). This factor is the ratio between the $T_{10}$ for a particular tank and the theoretical maximum detention time in that tank (Volume ($m^3$)/Flow ($m^3$/min)).

While there are limitations to this approach, the application of the simple baffle factor will focus attention on the limitations of structures used throughout Australia for disinfection. While tracer studies will undoubtedly provide more reliable data, they are expensive and it is unreasonable to expect that they would be applied widely throughout Australia.

*Table 1. Baffle factor definitions (taken from USEPA Guidance Manual for Disinfection Profiling and Benchmarking, 2003)*

| Contact Tank Type | Tank Description | Baffle Factor |
|---|---|---|
| **Un-baffled (mixed flow)** | None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities. Can be approximately achieved in flash mix tank. | 0.1 |
| **Poor** | Single or multiple un-baffled inlets and outlets, no intra- basin baffles. | 0.3 |
| **Average** | Baffled inlet or outlet with some intra-basin baffles. | 0.5 |
| **Superior** | Perforated inlet baffle, serpentine or perforated intra- basin baffles, outlet weir or perforated launders. | 0.7 |
| **Perfect (plug flow)** | Very high length to width ratio (pipeline flow), perforated inlet, outlet and intra-basin baffles. | 1.0 |

*Example*

Consider a tank with no baffles on the inlets or the outlets and no baffles in the tank, and a theoretical detention time of 40 minutes. From Table 1, a baffle factor of 0.3 is appropriate. The $T_{10}$ can then be calculated as

40 x 0.3 = 12 minutes.

12 minutes is the value that can then be used to calculate the Ct.

This value can then be compared with tables of log removal and Ct for different pathogens provided in many references e.g. AWWA (2001) or ADWG (2011).

An account of optimising chlorine contact tank performance can be found in Church and Colton (2013). Further information on all aspects of Ct is also available in Lanchberry (2019).

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