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

Research Project 1074

Water for the wellbeing of all Australians

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WATER SERVICES ASSOCIATION OF AUSTRALIA

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

Final Report – WaterRA Project 1074

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Cover photo of the Morgan water treatment plant, courtesy of SA Water

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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WaterRA Project No.	1074 – Good Practice Guide to the Operation of Drinking Water Supply Systems for the Management of Microbial Risk

GLOSSARY

ADWG	Australian Drinking Water Guidelines
AWWA	American Water Works Association
BAC	Biological activated carbon (check)
BFPD	Backflow prevention device
C.*t* factor	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
HBT	Health based target
HPC(22)	Heterotrophic plate counts measured at 22^{o}C
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
USPEA	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 2008). 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 regulation into improved operational practice.

The main purpose of this Guide is to provide senior managers and operational staff of drinking water utilities 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.

Expert advice should be sought for WTPs whose design or operation varies substantially from those described in this Guide.

CONTENTS

INTRODUCTION

Purpose of 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 informed by 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 done, 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.

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; it will also assist utilities meet any future microbial health-based targets that may be includes in the ADWG.

The Guide is presented in a tabular format for simplicity. The table is broken into sections that relate to the key control points 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 ramifications for consumers, water utilities and governments are severe.

Pathogens pose the greatest and most tangible risk to drinking water safety (NHMRC and NRMMC, 2011), 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 (WWTPs), 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 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 WTP waste streams such as clarifier sludge supernatant and backwash water are returned to the upstream reservoir or the head of the 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 (CCP), the following actions are required:

- establish target criteria and critical limits for the treatment process (ADWG section 3.4.2);
- prepare and implement operational procedures (ADWG section 3.4.1) and operational monitoring (ADWG section 3.4.2) for the process;
- prepare corrective action procedures (ADWG section 3.4.3) in the event that there are excursions in the operational parameters; and
- provide employee training (ADWG section 3.7.2) 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 may be required to control the different types of 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 success with *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 more 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.* 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.

Currently, on-line monitoring of filtered water turbidity is the only *practical* way to continuously monitor the performance of a WTP to optimise the removal of protozoan pathogens. 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 WTP can be significant. Several filters could comply with prescribed turbidity targets, while others may fail to meet the requirement by a significant margin.

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 chlorine, chloramine or ozone, or more recently irradiation, using UV light. More information on the strengths and weaknesses of various disinfectants can be found in Information Sheets 1.1 to 1.7 in the ADWG (NHMRC and NRMMC, 2011).

Even after the treatment processes at the WTP results in the production of safe drinking water, once the water leaves the WTP 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).

BASIS OF THIS GUIDE

This Guide has been written based on the processes typically found in conventional WTPs, including chemical pre-treatment, coagulation, flocculation, clarification, media or membrane filtration, and disinfection (chlorine-based chemicals and/or UV irradiation). It does not consider ozone or biologically-activated carbon (BAC), or the dosing of chemicals such as potassium permanganate, powdered or granular activated carbon (PAC/GAC), lime and fluoride.

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 WTP 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; and
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 WTPs have identified a number of high risk conditions and practices that can lead to a reduction in pathogen removal. 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 source. 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; and
4. Poorly managed recycled waste streams (e.g. waste backwash water and sludge thickener supernatant) returned to the head of the WTP, or the reservoir supplying the WTP, 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. Contamination can also occur in treated water storages as a result of birds, reptiles or vermin 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;
- 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
- the implementation of hygienic work practices.

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 manage the risks to the water supply
- Amber A **Supporting** Measure for one or more of the Required Measures
- Green A **Desirable** Measure

For the **Required Measures**, additional information relating to the *Frequency and Measure of Assessment* and the *Required Result* are provided. This additional information is also provided for most of the **Supporting Measures***,* but not for the **Desirable Measures**.

Many of the **Required Measures** are one-off requirements; that is, items that will be established or carried out during the initial optimisation of a WTP. However, there are other **Required Measures** where regular assessment and reporting are required. The first type of **Required Measures** are marked as "One Off" in the Table. The others have specific information included regarding the recommended frequency of assessment and/or reporting.

For each part of the water supply system that is described in the Table, the Measures have been grouped by colour, and within each colour by the *Frequency and Measure of Assessment*.

By providing *Frequency and Measure of Assessment* and a *Required Result* the intent is that the results will be incorporated into the water utilities' drinking water quality reporting framework. Such reporting should include not only those Measures with numerical results attached to them but also observational monitoring since this is just as important as numerical reporting in the management of risks to public health.

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.*

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.

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 WTP maximises the removal of pathogens.

Ideally, during periods when raw water is of a consistent quality, a WTP 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 WTP 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.

Measure	Rationale	Frequency and Measure of Assessment	Required Result
There are no interconnections between treated water and any raw or partially-treated water.	A thorough review of old and new pipework and valves at a WTP may identify interconnections or possible interconnections. Any actual or potential connection between fully treated drinking water and non-potable water should be fully isolated to prevent recontamination. Such isolation should be by removal of a section of pipe or the installation of a "double block and bleed" system.	***One off*** Should be reassessed after any major refurbishment or capital works.	Interconnections should be removed completely and the ends blanked off, or a double block and bleed system installed. Appropriate labelling and signage should be in place clearly stating such systems should only be opened when instructed by the relevant operations manager with the notification of the relevant health regulatory body.
Utility plant operators receive formal and preferably accredited training on all the unit processes employed at their plants.	Training is essential for competent operation of a WTP. Training should be to a level of technical competency appropriate for the risk at a particular plant.	***Annual Review*** Training assessment gap analysis reported.	All staff operating WTPs have the necessary qualifications as defined by the National Competency Framework or relevant state requirements. The gap analysis includes the number of operators with the necessary qualifications and for those without, the specific units of competency that are lacking.

	Plant operators have experience appropriate to the level of risk managed by the plant.	Adequate experience is necessary to facilitate the management of a WTP during periods of change and in the solving of problems. Operators at higher risk plants require greater experience.	***Annual Review*** Experience assessment gap analysis reported.	All staff operating WTPs have the experience as defined by the National Competency Framework or relevant state requirements to support their formal qualifications.
	Plant operation should be continuous where possible.	All plants stabilise and produce better quality water with continuous operation. Any plant with a clarifier sludge blanket 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. 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. Continuous operation can usually be achieved by: • Reducing the flow rates through the WTP • Altering stop/start levels in treated water storage tanks • Smart use of distribution storages to supply the daily demand patterns thereby limiting demand changes at the WTP • Reducing the numbers of process trains on line at any one time • Installing variable speed drives (VSDs) on raw water and treated water pumps • Ensuring chemical dosing pumps are sized appropriately Where a plant cannot achieve continuous operation, then a WTP should target single runs of 8-24hrs, and an absolute minimum run time of 4 hrs.	***Monthly*** *Average daily operation (%)* Monthly average of $\frac{\text{Hours operated per day}}{24} \times 100$ (Note: If the plant is not operated on a day, it should not be included in the calculation) *Average daily plant starts* Monthly average of (Plant starts per day)	As close to 100% as possible. As close to zero as possible. Zero denotes continuous operation.

General Water Treatment Plant Operation continued				
	Measure	**Rationale**	**Frequency and Measure of Assessment**	**Required Result**
	All pits, pipes, valves, dosing points and sampling points, including the direction of flow in pipes, are clearly labelled. 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. Labelling also aids in the training of new operators.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies
	The WTP is operated and attended for a significant part of its run time during daylight working hours.	Plants run at night only, or unattended, cannot be adequately checked or their performance assessed unless reliable advanced systems are in place to allow rapid intervention should an anomaly be detected by automated sensors. The WTP 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.	***Annual Review*** Of attendance at plant whilst it is running.	Complies
	There is appropriate duty/standby capability provided for all critical components, such as chemical dosing pumps and backwash pumps to allow the plant to continue to operate optimally.	Attempting to operate a plant with less than the necessary equipment, compromises pathogen removal.	***Annual Review*** Of duty/standby capability.	Complies
	Where intermittent operation of a WTP is unavoidable, any filter having accrued >75% of design terminal headloss is to be backwashed prior to start up (AwwaRF 2002), or the filter must	Start-up of a heavily laden filter poses an unacceptable risk of turbidity and pathogen breakthrough.	***Annual Review*** Of design terminal headloss of filters.	Complies

	be subjected to slow start-up over a period of approximately 30 minutes (AWWA 2001). Where operation is such that the plant only operates 2-3 days per week then a backwash should occur prior to shutdown.			
	Flow split to downstream process units (flocculation bays, clarifiers and filters) is (AWWA 2001) within 5% of the average.	Unequal flows can result in differential and poor performance of individual process units.	***Annual Review*** ***Continuous Monitoring*** using flow meter trends for individual process units.	Records confirm testing and any action resulting.
	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 WTP .	A useful tool for any operations team, particularly during water quality incidents and emergencies is an up-to-date, informative Operating Manual. The manual includes 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.	***Annual Review*** Review of the manual to ensure it is up to date.	Complies
	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*** Filter outlet valves position operate within +/- 5% of setpoint.	Complies
	Tank walls and channels are clean.	The build-up of sludge or biological growth on structures in a WTP can compromise the operation of the WTP particularly when it carries over on to the surface of the filters. It can also compromise operation of online monitoring instruments.	***As Required*** Tank wall and channel cleaning should be done as regularly as is necessary to avoid the build-up of sludge and/or biological growth.	

Raw Water Extraction and Storage Systems

Introduction

After rainfall, pathogens may wash into creeks, rivers and reservoirs, increasing the pathogen load entering the WTP. 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 WTP should be reduced for as long as possible until monitoring of raw water quality signals a return to more average operating conditions.

Measure	Rationale	Frequency and Measure of Assessment	Required Result
Online monitoring is provided at the raw water offtake or higher in the catchment for early warning of changes.	Early warning of changes in the nature and quality of the water entering the WTP allows time for appropriate action to be taken by the operations team. Appropriate actions include: • Jar testing and adjustment of chemical dosing rates based on the jar testing results • Down rating (i.e. reducing flow) or stopping the WTP • Utilising alternative water sources • Filling off river raw water storages or treated water storages Monitoring typically includes turbidity, pH, conductivity, rainfall and river flow. In the case of reservoir monitoring, redox, temperature or dissolved oxygen (DO) can provide early warning of turnover events. Newer instruments are available to monitor DOC and colour and possibly chlorophyll *a*. In a run of river system, development of	**One off** ***Annual Review*** Including records of calibration and maintenance as per the manufacturer's recommendations.	Present

		communication protocols with WTPs further upstream can also provide early warning of changes.		
	Travel time of raw water from the source to the WTP is known for various plant flows.	Allows the operations team to accurately plan and prepare for changes in raw water quality arriving at the WTP.	***One off*** Preparation of a flow vs travel time table and included in an Operating Manual.	Reported and included in the Operating Manual.
	Detention time in raw water storages is maximised and short circuiting is minimised.	Pathogen load can be reduced using the natural processes of settling and UV disinfection (Toze et al 2012; and Hipsey et al., 2003 & 2005).	***Annual Review*** Of potential for short circuiting.	Records confirm inspections.
	Raw water extraction points and their immediate locale should be regularly inspected for sources of contamination.	Inspection allows identification of contamination sources. Bore integrity should be included in the inspections and any flooding risk minimised.	***Monthly*** Inspection of extraction points.	Records confirm inspection and timely management of any sources of contamination.
	Where alternative offtakes are provided, the most suitable offtake is used at all times.	Where alternative sources or alternative offtakes are available, the quality of the water at the different sources should be actively monitored (online, grab or a combination of both) at an interval appropriate to detect changes. The most appropriate source should be selected based on chemical parameters including DOC, the likely pathogen and cyanotoxin load, and the treatability of the water as determined by jar testing.	***As Required*** Monitoring should be undertaken at an interval appropriate to detect changes.	Records confirm monitoring and appropriate selection of offtake.

Raw Water Flow Management

Introduction

Changes in flow rate affect all aspects of a WTP. Chemical dosing must be changed 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.

	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	Raw water flow rate increases at start up, or during operation, should be <3% per minute with a critical limit of 5% (AwwaRF 2002).	Flow rate increases >3% per minute tend to 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. The impact can often be seen with turbidimeters but certainly with particle counters. Weak floc is more susceptible to rate changes. Rapid changes in flow rate may also adversely impact on clarifiers and possibly disinfection and chemical dosing systems.	***Monthly*** Number of flow rate changes <3% x 100 Number of flow rate changes Number of flow rate changes >5% x 100 Number of flow rate changes Needs to include all flow rate changes of any duration since even short spikes can cause particle shedding and increased pathogen risk.	> 95% 0%

Residuals 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 the impact on the performance of the WTP.

	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	Any water returned to the head of the WTP must occur upstream of all processes designed to remove solids from the raw water, in particular coagulant dosing. Any return must be well mixed with the raw water entering the WTP (AWWA 2001). The coagulant dose should be adjusted for the additional flow and load to ensure coagulation is optimised.	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. Coagulation cannot be optimised if the return point is after the point of coagulant addition. 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.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies
	The flow rate of return streams to the head of the plant should be continuous with a target <5% of inflow and a critical limit <10% of inflow (AWWA 2001).	Intermittent return flows make it very difficult to optimise coagulation and create a high risk of pathogen breakthrough.	***Monthly*** No. of recycle flow periods Qr <5% x 100 No. of recycle flow periods Total time recycle flow operates Total time plant operates	% <5% = 100% As close to 1 as possible.
	The turbidity of any wastewater recycle is monitored (AWWA 2001) and the recycle shut down if >20NTU.	Recycled water from waste streams is likely to have an increased pathogen load derived from degraded floc/sludge. Elevated turbidity increases the difficulty of effectively treating any waste stream.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies
	In high risk catchments, for example, Category 4 catchments as defined in WSAA's HBT Manual (WSAA 2014), 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 WTP in a high risk catchment is likely to contain a higher concentration of pathogens. The water is therefore unsuitable for reuse except after appropriate treatment. Appropriate treatment may be ultraviolet (UV) irradiation, ozonation or membrane filtration.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies

Coagulation

Introduction

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

Measure	Rationale	Frequency and Measure of Assessment	Required Result
A well designed mixing system (static or mechanical) is provided for coagulant addition. This may include a long section of pipe with multiple bends and fittings.	Optimised coagulation is absolutely dependent on rapid and thorough mixing between the coagulant and the raw water.	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
Appropriately sized, graduated calibration tubes, calibrated flow meters or mass flow meters are provided to measure the amount of coagulant dosed (AwwaRF 2002).	Accurate dosing of coagulant is essential to maintain optimised coagulation. (Calibration tube size should be such that in one minute the liquid drops a distance at least equal to the diameter of the tube.)	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
There is a system to detect the loss of coagulant dosing.	Compromised or failed coagulation results in reduced pathogen removal. Methods of detection include flow meters, SCDs, pH meters and flow switches. Level sensors in storage tanks can assist in detecting major loss of coagulant dosing.	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
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. Changed conditions require reassessment of the optimum pH.	***Weekly*** for run of river plants ***Monthly*** for reservoir plants Total pH obs outside optimum pH range x 100/ Total observations	pH is within the required range 95% of the time. e.g. for alum this is likely to be +/-0.2 pH units.
Volumetric or draw down checks of the coagulant dose rate are performed and the dose is verified +/- 5% of the setpoint.	The actual dose delivered should be checked to ensure optimised coagulation is maintained.	***Weekly*** Total measurements where dose > +/- 5% x 100/Total number of measurements	Coagulant dose is within +/- 5% of setpoint 95% of the time
Dilution of coagulant with carrier water is at least 10:1, and	Dilution assists even dispersion and mixing which is essential for optimised	***One off*** And whenever modifications are made to	Complies

	preferably less than 20:1.	coagulation. Over-dilution can compromise coagulation.	the chemical dosing system.	
	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.	***One off*** Reviewed when a new chemical is introduced or there is a significant process change.	Reported and included in the Operating Manual.
	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 an indication, jar testing should be carried out for run of river systems once per week and reservoir systems once per month.	***Weekly*** for run of river plants ***Monthly*** for reservoir plants Note that more frequent jar testing will be required during periods of change.	Records confirm full and complete jar tests conducted at the required interval.
	Post-coagulation concentration of soluble Aluminium (Al) or Iron (Fe) is <0.1 mg/L (Murray et al. 1999).	Reflects optimised coagulation (pH, alkalinity and coagulant dose and type) and higher results indicate sub optimal coagulation. This can be measured most easily on the water leaving the filter.	**Weekly** and after a change in coagulant dose No of measurements <0.1 x100 Total number of measurements	%<0.1 = 95%
	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 check whenever a flow rate change occurs.	Complies
	Records of jar testing and chemical dose changes are compiled and kept (AwwaRF 2002).	Historical data can allow for more rapid response to changes.	***Annual audit*** Of jar test results.	Annual audit confirms full and complete jar tests conducted and outcomes acted on.
	Operators respond proactively to changed raw water conditions using a look up table (alum and polymer doses related to raw water turbidity, DOC, colour and temperature) or instruments (SCD, Zeta potential or spectroscopic systems) (AwwaRF 2002).	During changing conditions, rapid responses are necessary to avoid unsafe water leaving the WTP.		

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	Frequency and Measure of Assessment	Required Result
	Flocculation time is between 5 and 45 minutes depending on water temperature.	Water temperature has a significant effect on flocculation. The critical transition temperature between slow and faster flocculation is around 10-12^{o}C.	***One off*** Preparation of a flow vs flocculation time table and included in an Operating Manual. Should be reassessed after any major refurbishment or capital works.	Reported and included in the Operating Manual.
	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.	***Annual*** Should be reassessed after any major refurbishment or capital works.	Reported and included in the Operating Manual.
	Flocculation tanks are kept free of accumulated compacted sludge.	Sludge accumulation results in a reduction of the floc basin size and potential carryover of anaerobic “lumps” to the filters on start-up.	***Quarterly*** Inspection of flocculation tanks for compacted sludge.	Records confirm inspection and any action taken.
	For gravity systems, large settleable floc (1.5 to 5mm) is present. For DAF systems, medium floc (0.5 – 1.0mm) is present. 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*** Inspection of flocculation bays whenever jar testing is carried out.	Records confirm inspection and any action taken.
	Flocculators run continuously (24/7) (AWWA 2001).	Intermittent operation allows settling of floc and compaction, resulting in a reduction of the floc basin size and potential carryover of anaerobic “lumps” to the filters on start-up.	***Daily*** Inspection records to confirm flocculators ran continuously.	Complies
	Uniform floc present in a clear water background (not hazy or cloudy) leaving the flocculation zone or on top of the filters (AwwaRF 2002).	Uneven floc size, or a muddy/turbid background indicates poor coagulation and/or poor flocculation which may result in reduced pathogen removal.		

Clarification

Introduction

Primary solids and pathogen removal step.

	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	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.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies
	Clarified water turbidity target <2 NTU. Critical limit for a clarifier of 5 NTU (AWWA 2001) and DAF 3 NTU. Online monitoring is recommended. If manually monitored, daily testing is required as well as during clarifier disturbances.	Consistent, optimised performance of the clarification system reduces the load on the filters allowing longer and stable filter run times.	***Monthly*** $\frac{\text{No. observations <2 NTU}}{\text{Total number of observations}} \times 100$ $\frac{\text{No. observations <5 NTU}}{\text{Total number of observations}} \times 100$ $\frac{\text{No. observations <3 NTU}}{\text{Total number of observations}} \times 100$	<2 NTU >=95% <5 NTU 100% <3 NTU 100%
	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 of clarifier overflow. Inspection should occur at different times of the day particularly during hot and or windy weather.	Records confirm inspection and any action taken.
	Solids contact and sludge blanket clarifiers are not subjected to stop/start operation. Solids contact clarifiers can be operated intermittently, if the mixers remain on continuously.	Stop/start operation allows for the settling of sludge and results in poor operation of the clarifier after start up.	***As required***	Complies

Media Filtration

Introduction

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

Measure	Rationale	Frequency and Measure of Assessment	Required Result
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.	***One off*** Review annually. Could be calculated continuously and alarmed in the SCADA system.	Complies
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 specifications.	Allows assessment of individual filter performance and detection of poorly performing filters.	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
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 of pathogens at this stage is very low.	***Annually*** Also after any major refurbishment, capital works or PLC modifications.	Complies
Combined air scour low rate wash if present is < 15 m/hr.	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*** Flow rate assessment needs to be repeated if modifications are made to backwash system or controls.	Complies
During drain down, prior to backwashing, controls are in place to ensure the filtration rate does not increase.	Any increase in flow through a filter particularly at the end of a filter run results in particle and pathogen shedding.	***Annual Review*** Also after any major refurbishment, capital works or PLC modifications.	Complies
A full filter inspection (including, where relevant, the plenum space) is carried out at least once per year (Kawamura 2000) or after significant dirty water events.	Filter media and underdrains can deteriorate significantly and compromise filter performance. Details of a full filter inspection can be found in Mosse and Murray (2009).	***Annually*** Also to be done after a significant dirty water event.	Complies

	Media depths in all filters are within specifications.	Loss of media in any filter increases the risk of turbidity and pathogen breakthrough.	***Quarterly*** For each filter Distance to top of media x 100 Specified distance to top of media Alternatively, the media depth can be assessed based on lines painted on the walls of the filter indicating the specified bed depth.	< 115% >90%
	Filter operations must be optimised to remove pathogens, as measured by post-filter turbidity. Examples of post-filter turbidity performance which would deliver known log removal credits for the removal of *Cryptosporidium* (WSAA 2014) are given below: Individual filter turbidity ≤0.15 NTU for 95% of the month and not >0.3 NTU for ≥15 consecutive minutes. (4.0 log removal for conventional treatment 3.5 log removal for direct filtration) Individual filter turbidity ≤ 0.2 NTU for 95% of the month and not > 0.5 NTU for ≥15 consecutive minutes. (3.5 log removal for conventional treatment 3.0 log removal for direct filtration)	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. Water from individual filters should consistently produce water that has a turbidity of <0.2 NTU. The ADWG contains target values for post filter turbidity. The actual target values for post filter turbidity that will be applicable for an individual WTP will depend on the source water assessment (WSAA 2014).	***Monthly*** No. observations < target NTU x 100 Total number of observations No. observations < critical NTU x 100 Total number of observations	≥95% < target NTU value 100% < critical NTU value

Media Filtration continued				
	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	Backwashes are triggered automatically by turbidity, head loss and run time (Kawamura 2000).	All three triggers should be *enabled* to provide adequate protection against the passage of pathogens. Triggers are sometimes turned off for "convenience".	***Monthly*** Check backwash triggers.	Complies
	Clean bed head loss (CBHL) is monitored during operation and trended.	Any sustained increase in CBHL indicates fouling of the media and likely 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 original CBHL.	100 % within 5% of original CBHL
	Backwashing of dual media filters should achieve >15% expansion of the filter coal, and fluidisation of the full filter media depth (AwwaRF 2002; AWWA 2001).	Poorly backwashed filters result in reduced plant capacity and pathogen removal. Methods for measurement of fluidisation and expansion can be found in Mosse and Murray (2009).	***Monthly*** For each filter Media fluidisation depth >95% Coal expansion >15%	Complies
	Backwashing of mono-media sand filters with water or combined air and water should achieve >5% bed expansion and some fluidisation of the bed.	Poorly backwashed filters result in reduced plant capacity and pathogen removal. Methods for measurement of fluidisation and expansion can be found in Mosse and Murray (2009).	***Monthly*** For each filter Fluidisation depth >20% Expansion >5%	Complies
	During backwashing, 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.	***Monthly*** No. backwashes where flow increase <20% x100 Total backwashes	100% backwashes

	In plants without filter to waste, the ripening period after backwashing does not exceed the critical limit for any longer than: 0.5 NTU 30 min (3 log credit) 0.5 NTU 15 min (3.5 log credit) 0.3 NTU 15 min (4 log credit)	Any increase in turbidity represents increased risk to consumers. The ripening period is generally associated with a lower log removal of pathogens. 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. Number of ripening periods < target x100 Total number of ripening periods	> 95%
	Continuous recording and display of turbidity, filter flow, head loss and filter level or filter outlet valve position, is provided on the plant SCADA.	Essential for filter optimisation and problem diagnosis.	***Daily*** review of trends. ***Annual*** review of SCADA set up.	Present
	Air scouring is required 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. Air scouring may also be required in some plants not using polymer, eg Iron (Fe) and Manganese (Mn) removal plants.	***One Off*** At time of commissioning of filters.	Present
	Filters are drained (or in the case of pressure filters drained and opened) quarterly and a surface inspection carried out (AwwaRF 2002). N.B. Surface inspection does not require entry to the filter.	Filter media can deteriorate significantly and relatively rapidly resulting in compromised filter performance.	***Quarterly*** or after a significant dirty water event.	Records confirm inspection and any actions taken.
	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 is associated with an increased risk of the passage of pathogens.	***Monthly*** Review of backwash profiles.	Complies
	A backwash is observed on each filter at least once per month (AwwaRF 2002).	Without careful observation, backwash deterioration will not be detected.	***Monthly*** A backwash is observed.	Records confirm observation.

Media Filtration continued				
	Measure	**Rationale**	**Frequency and Measure of Assessment**	**Required Result**
	Flow through the turbidimeters is within manufacturer's recommended ranges and is checked regularly.	Zero 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.	Records confirm checks.
	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.	***As Required***	Complies
	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.		
	Where particle counts are used, the target for particles in the size range 2-15µm is <20/mL, with a critical limit of <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. Particle count checks are recommended for a WTP treating high risk water.		

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 WTP, it is not an effective barrier for protozoan pathogens.

	Measure	Rationale	Frequency and Measure of Assessment	Required Result
CHLORINATION AND CHLORAMINATION				
	Primary disinfection is based on achieving a minimum target of T_{10} contact time for the ambient temperature and pH at all times. Calculation of C*t* takes into consideration the contact tank baffling factor (see Appendix 1).	Control of pathogens using chlorine-based disinfectants is determined by a C*t* value, not free chlorine residual. The necessary T_{10} to control pathogens is dependent on temperature and the free chlorine residual corrected for pH. The use of a baffling factor is satisfactory; however more reliable data can be obtained using tracer studies or computational flow dynamics.	***Monthly*** No. observations with C*t* ≥ target x 100 Total observations No. observations with C*t* > critical x 100 Total observations	>95% 100%
	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. Online monitoring and PLC interlock with the treated water pump(s) is essential to ensure this.	***Monthly*** No. observations with C*t* < critical x 100 Total observations	0%
	Short circuiting is minimised in the contact tank and in treated water storages.	Short circuiting compromises achievement of C*t* and also increases residual decay.	***One off*** Assessment that short circuiting is not occurring.	Records confirm checks.

Chlorine-Based Primary Disinfection continued				
	Measure	**Rationale**	**Frequency and Measure of Assessment**	**Required Result**
CHLORINATION				
	Free chlorine residual is monitored at the primary dosing point using online instruments.		***One off*** Should be reassessed after any major refurbishment or capital works.	Present
	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.	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
	pH is monitored on line 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.	***One off*** Should be reassessed after any major refurbishment or capital works.	Present
CHLORAMINATION				
	Online monitoring for chloraminated systems includes total chlorine and monochloramine concentration.	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.	***One off*** Verify that online monitoring includes all necessary parameters.	Present
	The chlorine to ammonia ratio is determined regularly.	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. The necessary ratio can vary and is affected	***Weekly*** Check chlorine to ammonia ratio.	Complies

		by the pH and temperature.		
	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*** No. measurements >90% x 100 Total measurements	90%
	Initial dosing of chlorine and ammonia is set to achieve a free ammonia <0.2 mg/L 90% of time.	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. High free ammonia encourages nitrifying bacteria to become established.	***Weekly*** No. measurements <0.2 x 100 Total measurements	90%
	Free ammonia, nitrite and nitrate are monitored frequently.	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*** during critical periods of high temperatures, low pH or long detention times. The frequency can be decreased during periods when nitrification is less likely.	No increase
	pH, temperature and DOC are monitored frequently.	Low pH, warmer temperatures (>15^{o}C) and increases in DOC can lead to loss of residual and nitrification.		

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	Frequency and Measure of Assessment	Required Result
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.	***Prior to installation*** Check that the system is a validated system.	Certified validated system.
The UV system operates at ≥ design UV transmittance (UVT - %).	Operation outside the design specifications will not result in the required log removal of pathogens.	***Monthly*** $\frac{\text{No. observations} \geq \text{design T}}{\text{Total observations}} \times 100$	100%
The UV system operates within design specifications for UV intensity (I).	Operation outside the design specifications will not result in the required log removal of pathogens.	***Monthly*** $\frac{\text{No. observations} \geq \text{design I}}{\text{Total observations}} \times 100$	100%
The UV system operates within design specifications for flowrate.	UV systems are validated in terms of minimum and maximum flow rates (L/s).	***Monthly*** $\frac{\text{No observations} \leq \text{design flow}}{\text{Total observations}} \times 100$	95%

Membrane Filtration

Introduction

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	Frequency and Measure of Assessment	Required Result
	Approved (USEPA 180.1 or ISO 7027) turbidimeters are provided and installed and operated according to the manufacturer's specifications.	Allows assessment of performance.	***Design*** Check that approved turbidimeters have been purchased and installed correctly.	Present
	Membrane type and chemical cleaning systems are compatible and appropriate.	Some membranes are very sensitive to different cleaning chemicals. Cleaning chemicals should be compatible with the particular membrane type and should also address the contaminants to be removed. Typically acid cleaning is for inorganic deposits, alkali or surfactant for organics, and disinfectants or oxidants for biological fouling.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies
	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. Periodic membrane autopsies may also be carried out to check for contamination of the membrane material.	***Annually*** Full membrane inspection is undertaken.	Complies
	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.	***One off*** SCADA check. ***Annual*** review. ***Monthly*** review of data.	Present

Membrane Filtration continued				
	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	The design flux rate is known and the plant operates within the design values.	Exceeding the design specifications may result in reduced log removal of pathogens. The flux is the amount of permeate produced per unit area of membrane surface per unit time and is usually expressed as $L/m^2/hr$.	***Review monthly*** That plant is operating within its design values.	Complies
	Individual train filtered water turbidity target of <0.1 NTU and critical limit of not >0.15 NTU for ≥ 15 consecutive minutes.	Maximum removal of pathogens requires the lowest possible filtered water turbidity. This is reflected in standards in other parts of the world.	***Monthly*** $\frac{\text{No. observations} < 0.1\text{NTU}}{\text{Total number of observations}} \times 100$	≥95% < 0.1NTU No periods of operation with turbidity >0.15 NTU for ≥ 15 consecutive minutes.
	Backwashes are triggered automatically on time and permeability.	Backwashes are triggered automatically on time and resistance (TMP) or permeability.	***Monthly*** Check that backwashes are triggered correctly.	Complies
	Trans-membrane pressure (TMP) is monitored during operation.	Excessive trans-membrane pressure indicates fouling and a need for backwash or chemical cleaning. Decrease in trans-membrane pressure indicates a loss of membrane integrity.	***Monthly*** Post backwash TMP is within 20 % of original TMP. $\frac{\text{No. observations} <20\%}{\text{Total number of observations}} \times 100$	100% < 20 %
	Normalised water permeability (NWP) (L/m^2-h-bar) is determined under standard pressure and temperature conditions.	$NWP = \frac{\text{Total permeate flow/total membrane area}}{\text{TMP}}$ The NWP values are compared to initial levels trended over time.	***Monthly*** The measured NWP should be within 20% of the membranes design NWP.	Complies
	Pressure decay testing (PDT) for direct membrane integrity assessment is carried out	Individual membrane fibres can rupture or block and need to be pinned. Sonic testing identifies which modules may be breached.	***Daily (or 24 hr run time)***	0 or if >0, records of repairs are maintained and the

	regularly and membrane fibres repaired immediately if PDT fails.		No. of failed decays tests.	subsequent PDT passes.
	There is a justifiable technical basis to the cleaning sequence.	The frequency of normal cleans and chemical cleans should be regularly checked and optimised. Membrane permeability and transmembrane pressure should be reviewed before and after cleaning.	***Monthly*** Check of membrane cleaning sequence.	Records confirm checks.
	Flow through the turbidimeters is within the manufacturer's recommended ranges and is checked regularly.	Zero 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.	Records confirm checks.
	Adequate pre-membrane treatment is provided for all anticipated contaminants.	Membranes can be damaged by grit or fragments of shells. 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. Damage, blocking or contamination of the membranes can lead to reduced performance and shortened life.	***As required*** Check membrane pre-treatment system.	Records confirm checks.
	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.		
	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.		

Equipment and Instrumentation

Introduction

Equipment and instrumentation is essential for operation of a WTP.

	Measure	Rationale	Frequency and Measure of Assessment	Required Result
	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 WTP.	***One off*** Review annually.	Present
	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.	***One off*** Review annually.	Present
	Online turbidity meters (complying with USEPA 180.1 or ISO 7027) are provided for each individual filter (ADWG 2011).	Continuous monitoring of filtered water turbidity from individual filters is the only practical way to monitor pathogen removal.	***One off*** Review annually.	Present
	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.	***One off*** Review annually.	Present
	Online instrumentation is installed according to the manufacturer’s specifications. Particular attention needs to be given to maintaining the ambient temperature within the range specified.	Many online instruments are located outside and exposed to the elements. Manufacturers often specify acceptable temperature ranges for operation.	***One off*** Should be reassessed after any major refurbishment or capital works.	Complies

	There is online monitoring of coagulation pH.	Optimised coagulation, which is pH sensitive, is essential for maximum pathogen removal. This is particularly important for alum.	***One off*** Review annually.	Present
	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: • Calibrated portable pH meter • Calibrated portable turbidity meter able to measure accurately below 1 NTU with 0.1 NTU accuracy • Operational jar test machine and matched "jars".	An operator needs to be able to respond rapidly to changes in source water quality and establish the optimum coagulation requirements.	***Annual Review*** That sufficient equipment is available to do jar tests.	Present
	A portable chlorine meter is provided.	Regular checking of chlorine residuals is a key component for ensuring adequate disinfection.	***Annual Review*** That portable chlorine meters are present and operational.	Present
	Online instruments are positioned as close as possible to the point of sampling. 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.	***Annual review*** Of sampling lines for online instrumentation.	Complies
	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 manufacturers*** $\frac{\text{No. of calibrations}}{\text{No. of calibration specified}} \times 100$	Annual reporting 100%
	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.	***Annual*** The critical parameter should be adjusted to be out of range and the full alarm response monitored. The primary contact should be instructed not to respond to check the escalation.	Records confirm checks and outcomes and any actions arising.

Equipment and Instrumentation continued				
	Measure	**Rationale**	**Frequency and Measure of Assessment**	**Required Result**
	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.		
	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.		
	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.	***Review regularly*** To ensure laboratory equipment and reagents are fit for purpose.	Records confirm checks.
	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.	***Review regularly*** To ensure sufficient spares are available.	Records confirm checks.

Distribution System

Introduction

Safe drinking water must be maintained through the distribution system. There is limited ability to reduce the levels of pathogens, particularly protozoan pathogens in a distribution system, therefore recontamination must be prevented.

Measure	Rationale	Frequency and Measure of Assessment	Required Result
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.	***One off*** Backflow prevention devices can fail, therefore a program of checking is strongly recommended. The interval depends on the nature of the raw water and the distribution system.	Present Records confirm checks and outcomes and any actions arising.
High risk BFPDs are tested 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*** $\frac{\text{No. of BFPD tested and passed}}{\text{Total BFPD}} \times 100$	100%
All treated water storages have: • Fully intact roofs that do not allow any runoff to enter the storage • Walls and screening to prevent access of vermin or ingress of faecal material • Any gutters that are designed to prevent ingress of water from the gutter • Overflow pipes and whirly birds with effective screening.	Treated water storages have been regularly and repeatedly identified as sources of contamination.	***Quarterly check*** Of treated water storages.	Records confirm checks and outcomes and any actions arising.

Distribution System continued				
	In chlorinated systems, a free chlorine residual (free available chlorine equivalent (FACE) corrected for pH) of ≥0.2 mg/L is maintained at the ends of the distribution system (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. It also assists in the management of biofilms and limiting regrowth of opportunistic pathogens. Higher levels may be necessary for control of specific microbes e.g. *Aeromonas* or *Naegleria.* The necessary concentration may also vary with water temperature.	***Weekly*** No. of measurements in DS ≥0.2 x100 Total measurements in DS (DS = Distribution system)	95%
	In chlorinated systems, a free chlorine residual is always maintained in all treated water storages.	Treated water storages have been regularly identified as sources of contamination. 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 above).	***Continuous*** using online monitoring	Records confirm checks.
	In chloraminated systems, total chlorine at the ends of the distribution system is maintained >1.0 mg/L.	Experience in Australia has shown a sustained residual above 1.0 mg/L minimises the risk of nitrification.	***Weekly*** No. of measurements in DS ≥1.0 x100 Total measurements in DS	>95%
	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. The interval can be decreased during periods when nitrification is less likely.	Records confirm checks.
	In chloraminated systems, the distribution system is operated to achieve the highest ratio possible of monochloramine to total chlorine throughout the system.	Low ratios of monochloramine:total chlorine in the distribution system indicates poor operation of the system. Likely causes are dirty mains and long detention times with stagnant water.	***Weekly*** Check monochloramine to total chlorine ratio.	Records confirm checks.

	In chloraminated systems the pH is maintained between 7.8 and 8.5.	pH <7.8 results in rapid decay of chloramine residuals and promotes nitrification.	***Weekly*** Check pH value.	Records confirm checks
	Treated water storages are regularly cleaned of sediments.	Treated water storages have been regularly and repeatedly identified as sources of contamination.	The necessary interval depends on the nature of the raw water and the control of coagulation at the WTP. Annual cleaning is recommended as a minimum.	Records confirm cleaning and outcomes and any actions arising.
	Hygienic work practices are applied during work on the distribution system. Ideally this requires separation of sewer and water maintenance. If this is not possible, full disinfection of all tools and equipment, workers' boots and clothing is required prior to working on potable water systems.	Failure of hygienic work practices can result in contamination of water supplied to consumers.	***On going*** Regular field audits should be carried out to confirm adherence to hygienic work practices.	
	If during mains repair, contamination may have occurred by, for example, potentially faecally contaminated soil or water entering the main, remedial action must be taken. 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 and disinfected with a free chlorine C*t* of at least 100 mg. min/L (AWWA (2015); Yang et al. (2015); Water Research Foundation (2014)). 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.	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.	***As Required*** Disinfection procedure to be carried out after each main repair where contamination is likely to have occurred.	Records confirm disinfection and any actions arising.

Distribution System continued				
	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 customers as well as potable water. Many old towns and cities have old pipework that predates a WTP, occasionally allowing raw water bypasses around a WTP. Potential cross connections include water mains running in the same trenches as sewer mains. Such cross connections have been consistently identified as a cause of outbreaks of waterborne disease. Decommissioned WTP and distribution systems assets, including storages, which have not been physically separated from the operational assets, are also a potential source of contamination.		
	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.		
	Air valves are situated so that they cannot become submerged.	Air valves are a potential source of contamination.		
	A critical limit for Heterotrophic Plate Counts (HPC 22^{o}C) of <500 counts/mL as a 95th percentile is applied in the distribution system (Mosse & Deere 2009; USEPA 2006; Mays 1999). A more stringent target of 100 counts per mL can be used (Mosse & Deere 2009).	HPC provide a measure of the cleanliness of the distribution system and can be a useful trigger for distribution system cleaning. Important also in minimising taste and odour and dirty water complaints.		
	In chloraminated systems the free ammonia is maintained <0.2 mg/L.	Free ammonia promotes nitrification.		

	Critical valves have been identified and are regularly exercised.	Critical valves must be operable at all times particularly during incidents.		

Water Quality Information Management

Introduction

Sustained optimised operation of a WTP 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	Frequency and Measure of Assessment	Required Result
	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. A hard copy of all critical setpoints should also be maintained at the WTP.	***On Commissioning*** And whenever any change is made to the control system.	Present
	Access to change critical alarm limits is restricted to authorised officers.	To protect public health, critical alarm limits must not be altered without approval.	***One off*** ***Annual review*** Of access to critical alarm limits.	Complies
	Multi-tiered alarms with the capability to shut down the WTP are in place for all control points monitored by online instruments.	Out of specification water must never leave the WTP.	***One off*** ***Annual review*** Of alarms.	Present
	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. SCADA systems need to be set up to allow extraction of meaningful data.	***One off*** ***Annual review*** Of long term SCADA trends.	Complies

Water Quality Information Management continued				
	Alarm limits in the PLC accurately reflect the targets and critical limits defined in the Drinking Water Quality Management Plan.	Operation of a WTP should reliably reflect the outcomes of the risk assessment process and the Drinking Water Quality Management Plan.	***Annual review*** Of alarm limits in PLC.	Complies
	Critical alarms are physically tested using, where appropriate, out of specification water samples e.g. 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.	***Six Monthly*** Testing of critical alarms.	Records confirm tests and outcomes and any actions arising.
	Statistical analysis of WTP unit process performance relevant to pathogen management is provided to senior management at regular intervals (AwwaRF 2002; AWWA 2001).	Only long term statistical data allows evaluation of WTP barrier performance. Reporting to senior management allows the focus to remain where appropriate. Two 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.	***Monthly*** Analysis of WTP unit process performance.	Results are compiled, and report compliance with filtered water turbidity targets (LRV) and disinfection targets to senior management.
	SCADA trend data and reports are analysed daily and actions initiated when necessary.	Sustained optimised plant operation requires timely analysis of time series trends.		
	Non SCADA water quality monitoring data is trended and analysed weekly.	Sustained optimised plant operation requires timely analysis of all monitoring data.		

APPENDIX 1. CALCULATION OF T10

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).

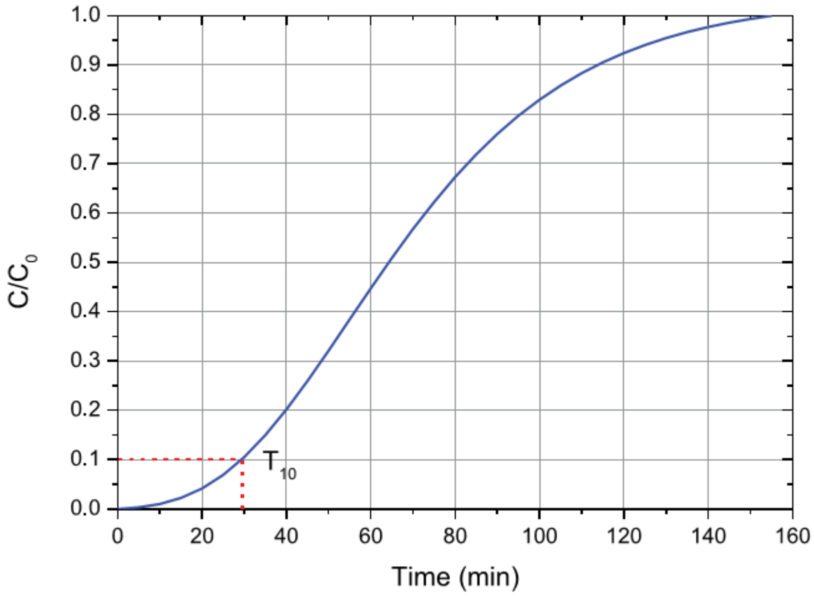

Figure 1. Step dose tracer test – cumulative distribution curve (taken from USEPA Guidance Manual for Disinfection Profiling and Benchmarking, 2003)

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).

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