Public Health Guidelines for Water Reuse and Stormwater Use

Alberta Health Services

Alberta

Reader Information
The Public Health Guidelines for Water Reuse and Stormwater Use have been developed with input from experts in water safety management, microbiology, water engineering and environmental public health, representing Alberta Health, Alberta Health Services, Alberta Environment and Parks, Alberta Municipal Affairs, Alberta Agriculture and Forestry, Concordia University of Edmonton and the University of Alberta. Alberta Health also consulted with City of Calgary, City of Toronto, Health Canada and the National Collaborating Centre for Environmental Health.

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Legal Disclaimer
The Public Health Guidelines for Water Reuse and Stormwater Use (Guidelines) are intended as a general resource only and are not meant to replace a party's investigation and analysis into the unique facts of their circumstances.

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Acronyms and Abbreviations

AEP	Alberta Environment and Parks
AHJ	Authority having jurisdiction
AHS	Alberta Health Services
AMA	Alberta Municipal Affairs
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BOD	Biological oxygen demand
C	Residual disinfectant concentration
CCP	Critical control point
CSA	Canadian Standards Association
ISO	International Organization for Standardization
LRC	Log_{10} reduction credit
LRT	Log_{10} reduction target
LRV	Log_{10} reduction value
MC	Management category
NIOSH	National Institute for Occupational Safety and Health
NSF	NSF International
ORP	Oxidation-reduction potential
PPE	Personal protective equipment
PPPY	Per person per year
QMRA	Quantitative microbial risk assessment
T	Contact time
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency
UV	Ultraviolet light
UVA	Ultraviolet light absorbance
UVT	Ultraviolet light transmittance
WERF	Water Environment Research Foundation
WHO	World Health Organization
WRSU	Water reuse and stormwater use
WSP	Water safety plan
WQMP	Water quality management plan

Terminology

Aesthetic water feature (end-use)	Water used for ornamental water features that are not designed for swimming and wading such as fountains, ponds, waterfalls and streams.
Agri-food irrigation (end-use)	Water used for irrigation of food crops.
Alternative water sources	Sources of water (not fresh surface water, reservoirs, or groundwater) that are used to offset the demand for freshwater (Sharvelle et al., 2017). Examples include municipal wastewater, stormwater, greywater, and rooftop collected rainwater.
Authority having jurisdiction	A Safety Codes Officer exercising authority pursuant to designation of powers and terms of employment in accordance with the Safety Codes Act.
Blended water	Various combinations of water derived originally from alternative water sources for use as a non-potable water supply (Sharvelle et al., 2017).
Challenge test	The evaluation of a treatment process unit for pathogen $\log_{10}$ reduction performance using selected surrogate or indigenous constituents. In general, a surrogate is introduced to the process influent, and the process influent and effluent flow are monitored for the concentration of the surrogate (Sharvelle et al., 2017). Challenge testing is done during the validation process.
Chloramine	A compound containing a chlorine atom bonded to nitrogen. Chloramines are formed when ammonia is added to chlorine to treat water or when chlorine is added to water in which ammonia is naturally present. Monochloramine (NH_2Cl), the main form of chloramine, is used for drinking water disinfection (Sharvelle et al., 2017).
Combined chlorine	The concentration of residual chlorine existing in water in chemical combination with ammonia and other organic compounds. Notably, of these residuals, only monochloramine (NH_2Cl) is a useful disinfectant (Sharvelle et al., 2017).
Commissioning	The activities associated with bringing the water reuse and stormwater use system into normal operation. Commissioning can occur for new systems or for those that are returning to operation after times of repair or shut down (Sharvelle et al., 2017).
Contact time (T)	The time required for disinfection to take place in a process unit (usually equivalent to the retention time required for 90% of the flow volume, as determined using a tracer study) (Sharvelle et al., 2017).
Cooling towers and evaporative condensers (end-use)	Water that is used to cool a water stream or building surface to a lower temperature. This includes water use in cooling towers as well as rooftop cooling systems.
Critical control point	Locations in a treatment train designed specifically to reduce pathogens.
Critical limit	A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability (NRMMC et al., 2006).
Cross connection	When a plumbing system allows water from one system (e.g., non-potable) to enter into another system (e.g., potable), resulting in the contamination of potable water (Sharvelle et al., 2017).
CT value	Disinfection residual concentration (C, in mg/L), multiplied by contact time (T, in minutes) at the point of residual measurement; a measure of disinfection effectiveness (US EPA, 1999).
Disinfectant	An oxidizing agent (such as chlorine, chlorine dioxide, chloramines or ozone) that is added to water and is intended to inactivate pathogenic (disease-causing) microorganisms.

Disinfection	The process designed to inactivate or destroy microorganisms in water. Disinfection processes include ultraviolet disinfection, chlorination, chloramination, chlorine dioxide, and ozonation.
Dust control / street cleaning (end-use)	Water deliberately applied to a ground surface to control dust emissions, clean surfaces, or both.
Exposure	Extent to which a stakeholder or stakeholders is subject to an event (International Organization for Standardization (ISO), 2009).
Faecal indicator	A biological, chemical, or physical marker of human and non-human faecal matter (Sharvelle et al., 2017).
Faecal indicator organism	A microorganism whose presence in water indicates the probable presence of faecal pollution and, therefore, possible presence of pathogens in the water (Sharvelle et al., 2017).
Fit-for-purpose	Water treated to a quality matching the quality requirements for the intended use of that water (Sharvelle et al., 2017).
Free chlorine	The concentration of chlorine in water that is present as hypochlorous acid (HOCl) and/or hypochlorite ion (OCl-).
Greywater (source water)	Domestic wastewater that does not include waste from toilets, urinals or kitchen sinks.
Groundwater	All water under the surface of the ground whether in liquid or solid state (*Water Act*, RSA 2000, c. W-3).
Hazard	Source of potential harm (ISO, 2009).
in situ	In the anticipated real life application.
Independent third-party	An independent third-party is a person who has no real or apparent conflict of interest regarding the water reuse and stormwater use project or the ultimate use of the treatment process unit being tested (State of Victoria, 2013).
Lagoon	Artificial pond for the storage, treatment, and stabilization of wastewater or effluent (Safety Codes Council, 2012).
Log_{10} reduction	A reduction in the concentration of a microorganism by a factor of 10. E.g., a 1-log reduction would correspond to a reduction of 90% from the original concentration. A 2-log reduction corresponds to a reduction of 99% from the original concentration (Sharvelle et al., 2017).
Log_{10} reduction credit	The number of credits assigned to a specific treatment process (e.g., microfiltration, chlorine disinfection, or ultraviolet disinfection), expressed in log units, for the inactivation or removal of a specific microorganism or group of microorganisms. A reduction of 90% would correspond to 1-$\log_{10}$ credit of reduction, whereas a reduction of 99% would correspond to 2-$\log_{10}$ credits of reduction (Sharvelle et al., 2017).
Log_{10} reduction target	The $\log_{10}$ reduction target for the specified pathogen group (i.e., viruses, bacteria, or protozoa) to achieve the acceptable level of risk to individuals (e.g., 10^{-4} infections per year or 10^{-2} infections per year) (Sharvelle et al., 2017).
Log_{10} reduction value	The $\log_{10}$ reduction demonstrated during treatment validation that corresponds to the level of removal or inactivation of microorganisms, such as bacteria, protozoa and viruses (Sharvelle et al., 2017).
Multiple barrier design	The use of treatment barriers in series such that the malfunction of one process does not compromise the performance of the entire treatment train (Sharvelle et al., 2017).
Municipal wastewater (source water)	Water that is collected on a municipal scale that represents a combination of black water (e.g. toilets and urinal water, kitchen sinks), greywater (e.g. bathroom sinks, showers, laundry), and other wastes from domestic, commercial and industrial sources. It is also referred to as sewage.
Non agri-food irrigation (end-use)	Water used for irrigation of non agri-food plant growth such as parks, recreation fields, golf courses, floral/tree gardens, ornamental plant greenhouses, turf production, and animal food crops.

Non-potable water	Water that does not meet Provincial or Federal drinking water quality guidelines and standards. (US EPA, 2012a).
Operational monitoring	The sequence of measurements and observations used to assess and confirm that individual barriers and preventive strategies for controlling hazards are functioning properly and effectively (State of Victoria, 2013).
Opportunistic pathogen	A pathogen that may cause disease in people with a weakened immune system, such as infants, pregnant woman, the elderly, smokers, and those undertaking immune-suppressant therapy. Various opportunistic pathogens may be present in source waters and/or in the environment and can grow in engineered water systems to numbers that may cause infection through dermal pathways (e.g., *Pseudomonas aeruginosa, Staphylococcus aureus, Mycobacterium avium* complex), inhalation pathways (e.g., *Legionella pneumophila, Mycobacterium avium* complex), or ingestion pathways (e.g., *Acinetobacter baumannii, Stenotrophomonas maltophilia*) (Ashbolt, 2015).
Ozone	Ozone is a gas, a strong oxidant, which may be used as a disinfectant when applied to water to inactivate bacteria, protozoa, and viruses (Sharvelle et al., 2017).
Pathogen	A disease-causing microorganism.
Peracetic acid	A strong oxidant formulated from hydrogen peroxide and acetic acid that is effective for the inactivation of bacteria, protozoa, and viruses (Sharvelle et al., 2017).
Potable	Water that is safe for human consumption (*Nuisance and General Sanitation Regulation,* A.R. 243/2003).
Potable reuse	Planned augmentation of a drinking water supply with reclaimed water (US EPA, 2012a).
Public health risk	Health risks to the general public resulting from accessibility or exposure to reuse water in a public place including but not limited to food facilities, housing, public institutions, recreational facilities and outdoor spaces, public swimming pools, work camps, community halls, schools, businesses, and large residential settings. Risks associated with single family, owner occupied homes, and occupational health risks may not be considered public health risks.
Reclaimed water	Treated alternative water sources of a quality suitable for a specific reuse (US EPA, 2012a). Also refers to alternative water sources that may not be treated but is applied in a manner that reduces public health risk to an acceptable level.
Recreational (end-use)	Water used primarily for activities in which the user comes in direct contact with the water for recreational purposes, either as part of the activity or incidental to the activity.
Reference pathogen	A reference pathogen is selected based on its possible presence in source water, a known infectious agent relevant to the community, and represents characteristics that make it a useful index of other pathogens in the same microbial group (Sharvelle et al., 2017). For these guidelines, *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, were used as reference pathogens for enteric viruses, parasitic protozoa, and enteric bacteria, respectively, to derive the $\log_{10}$ reduction targets for each combination of source water and end-use.
Risk	Effect of uncertainty on objectives (ISO, 2009).
Risk assessment	Overall process of risk identification, risk analysis and risk evaluation (ISO, 2009).
Rooftop collected rainwater (source water)	Precipitation from rain or snowmelt that is collected directly from a roof surface not subject to public access.
Runoff	Water that moves across (or through) soils on the land during snowmelt or rainstorms (Alberta Environment, 2008).
Stakeholder	Person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity (ISO, 2009).

Stormwater (source water)	Precipitation runoff collected from rain or snowmelt that flows over land and/or impervious surfaces in developed areas (e.g., streets, parking lots, and rooftops with frequent human access).
Surface water	Water bodies such as lakes, ponds, wetlands, rivers and streams, as well as groundwater with a direct and immediate hydrological connection to surface water (Alberta Environment, 2008).
Surrogate	A challenge organism (such as bacteriophage), particulate, or chemical (such as rhodamine) that is a substitute for the target microorganism of interest (State of Victoria, 2013).
Surrogate organism	An organism that behaves the same as the pathogen of interest in a treatment process. In the context of water reuse and stormwater use, surrogate organisms are used to verify the $\log_{10}$ reduction of pathogens in a treatment train (Sharvelle et al., 2017).
Toilet and urinal flushing (end-use)	Water used for toilet and urinal flushing.
Total Chlorine	The sum of free chlorine and combined chlorine.
Treatment process unit	A specific treatment step (for instance membrane filtration) that combines with other processes to constitute a treatment train (State of Victoria, 2013).
Treatment train	The complete sequence of treatment process units from source to end-use that the water undergoes to render it fit-for-purpose.
Ultraviolet disinfection	Ultraviolet (UV) light (produced from mercury vapor or LED lights) at germicidal wavelengths (typically, 254 nanometers, but also may include higher UV-C wavelengths from 255 to 328 nanometers). UV disinfection is effective particularly for the inactivation of pathogenic protozoa (Sharvelle et al., 2017).
Validation test	Detailed technology evaluation study conducted using challenge testing over a wide range of operational conditions, usually conducted at a pilot test facility, but can be done in situ (Sharvelle et al., 2017).
Vehicle wash wastewater	Water that is generated from washing domestic or light commercial vehicles (e.g., municipal buses), with little to no animal and/or agricultural transport or exposure. It is classified at same risk as rooftop collected rainwater.
Verification	An assessment of the overall performance of the treatment system and the ultimate quality of the product water being supplied to customers (NRMMC et al., 2006).
Water quality	Chemical, physical and biological characteristics of water with respect to its suitability for an intended end-use.
Water quality management plan	A plan that covers the assessment, design, treatment, monitoring, and management of water reuse and stormwater use systems. The plan should provide information to demonstrate that the processes and procedures used to treat, monitor, and distribute the alternative water sources ensure that the health-based targets specified in these guidelines are met.
Water reuse	When water is used again after its original intended purpose. The reuse can be for the same or a new purpose, and includes alternative water sources such as wastewater, greywater, and rainwater.

1.0 Introduction

There is growing interest in re-using wastewater or using stormwater for non-potable end uses, largely due to the economic and environmental benefits. Alberta is adopting a fit-for-purpose approach for the use of alternative water sources, whereby the water sources are treated to a quality acceptable for the intended end-use, posing an acceptable risk to the user, the public, and the environment.

The fit-for-purpose approach helps to minimize the costs of (unnecessary) water treatment, optimize energy usage, and potentially minimize the creation of other wastes (e.g. by-products of treatment). The *Public Health Guidelines for Water Reuse and Stormwater Use* (Health Guidelines) were developed to assess and manage the public health risks associated with using alternative water sources for non-potable uses where there is likely to be human exposure to the non-potable end-uses.

Applicants should read the Health Guidelines in their entirety prior to pursuing a project of this nature.

1.1 Purpose

The purpose of this document is to describe the public health risk-based assessment process and performance targets that can be used by applicants and regulators when developing and reviewing water reuse and stormwater use (WRSU) project applications.

The Health Guidelines are based on the principles of a water safety plan (WSP) which address how to comprehensively assess and manage risks from source to end-use (World Health Organization (WHO), 2005). By following the steps in the Health Guidelines, the applicant will create a water quality management plan (WQMP) that can support their project application.

1.2 Scope

The Health Guidelines explain how to assess and control for microbiological health hazards for combinations of water sources and non-potable end-uses where human exposure is probable. Five main categories of alternative source water (Table 1) and nine potential end-uses (Table 2) have been identified at this time. For the purposes of the Health Guidelines, alternative source waters are those not supplied from fresh surface water, reservoirs or groundwater. The end-uses were chosen based on projects that are expected or currently operating in Alberta. Potable water reuse is not included in the Health Guidelines. This document will be reviewed periodically to assess the inclusion of new water sources and end-uses.

A WQMP should be developed that covers the assessment, design, treatment, monitoring, and management of water reuse and stormwater use projects. The WQMP should provide information to support the use of an alternative water source, demonstrating that the water quality would consistently meet the health-based targets specified in these guidelines.

The health-based targets are applicable to public exposures and not occupational exposures. For WRSU projects that propose different source waters and/or end-uses than those described below, the Health Guidelines can be used as a tool to help guide the development of a WQMP.

The types of alternative source water are categorized by the quality of the water (i.e., pathogen composition and concentration) and the public health risk that each presents. Please note that the descriptions provided in Table 1 for each type of source water fall under the broad definitions in current regulations, but provide detail and nuance specifically for the purpose of addressing the pathogen risk by the subcategory of wastewater.

Table 1: Description of alternative source waters

Type of source water	Description
Municipal wastewater	Water that is collected on a municipal scale that represents a combination of black water (e.g. toilets and urinal water, kitchen sinks), greywater (e.g. bathroom sinks, showers, laundry), and other wastes from domestic, commercial and industrial sources. It is also referred to as sewage.
Greywater	Domestic wastewater that does not include waste from toilets, urinals or kitchen sinks. There are two categories of greywater determined by size of wastewater collection system: single family dwelling and multi-user buildings (section 2.1).
Stormwater	Precipitation runoff collected from rain or snowmelt that flows over land and/or impervious surfaces in developed areas (e.g., streets, parking lots, and rooftops with frequent human access). There are 2 categories of stormwater determined by the level of human sewage contamination (10^{-1} (10%) and 10^{-3} (0.1%) dilution) (section 2.1).
Rooftop collected rainwater	Precipitation from rain or snowmelt that is collected directly from a roof surface not subject to public access.
Vehicle wash wastewater	Water that is generated from washing domestic or light commercial vehicles (e.g., municipal buses), with little to no animal and/or agricultural transport or exposure.

Table 2: Description of end-uses

Type of end-use	Description
Aesthetic water features	Water used for ornamental water features that are not designed for swimming or wading such as indoor and outdoor fountains, ponds, waterfalls, streams, and living roofs and walls.
Agri-food irrigation	Water used for irrigation of food crops.
Vehicle washing	Water used for the purposes of washing cars, trucks, and other vehicles.
Clothes washing	Water used for mechanical laundering of clothes and other textiles.
Dust control / street cleaning	Water deliberately applied to a ground surface to control dust emissions, for street cleaning purposes, or both.
Cooling towers and evaporative condensers	Water used to cool a water stream or building surface. This includes water used in cooling towers as well as rooftop cooling

	systems. This does not include closed loop cooling systems where public exposure is improbable.
Non agri-food irrigation	Water used for irrigation of non agri-food plant growth such as parks, recreation fields, golf courses, floral/tree gardens, ornamental plant greenhouses, turf production, and animal food crops.
Recreational	Water used for recreational activities where the user comes in direct contact with the water, either as part of the activity or incidental to the activity (e.g., swimming, boating, canoeing, or kayaking).
Toilet and urinal flushing	Water used for toilet and urinal flushing.

The Health Guidelines do not provide guidance or information on:

a. detailed engineering design and technical standards for WRSU projects;
b. how to evaluate WRSU technologies;
c. direct or indirect potable reuse; nor
d. economic or financial feasibility of WRSU projects.

1.3 Project approval

The approval and coordination of WRSU projects throughout the province, potentially involves several stakeholders that could become involved depending on the source water and end-use. Please refer to the Water Reuse and Stormwater Use webpage for more information about legislative and regulatory requirements.

The inclusion of specific alternative sources of water and end-uses in this document does not mean that the various combinations are approved for use. There are other factors that could be considered by the approval agencies to determine whether alternative water sources can be used for non-potable end-uses. These factors include, but are not limited to:

a. water availability;
b. environmental conditions;
c. existing water management and land use policies;
d. other Acts and regulations; and
e. municipal requirements.

1.4 Approach to managing health risks

1.4.1 Health-based targets

The most significant human health hazards in non-potable WRSU projects are microbiological hazards that may lead to gastrointestinal disease (WHO, 2006). Enteric viruses, enteric bacteria, and parasitic protozoa have been detected in municipal wastewater, greywater, stormwater, rooftop collected rainwater, and vehicle wash wastewater. Exposure can occur at the endpoint through incidental ingestion of these waters and, to a lesser degree, through inhalation of aerosols or dermal contact.

There may also be instances where the source water contains high levels of chemicals that could impact health through the end-use. For these cases, the WQMP should identify the chemicals of concern, their risk to public health, and how they are managed. In this case, consult with Alberta Health Services or other relevant stakeholders before proceeding with the project proposal.

The risk assessment process begins with established health-based targets, which represent an annual tolerable infection risk from enteric pathogens. Alberta has adopted two health-based targets from the United States Environmental Protection Agency (US EPA): the one in 100 voluntary infection risk for recreational waters and the one in 10,000 involuntary infection risk for potable water (Schoen et al., 2017; US EPA 2003, 2012b). The health-based targets have been used to set system performance targets, which are referred to as $\log_{10}$ reduction targets (LRT), for each type of source water and end-use (WHO, 2011). The system performance targets may be met through treatment and/or exposure controls which have been assigned $\log_{10}$ reduction credits (LRC). Further details on health-based targets and the end-uses in Table 2 are found in Appendix A.

1.4.2 Water quality management plan (WQMP)

A WQMP should be developed for every water re-use project that presents a public health risk. These Health Guidelines apply the principles of a WSP approach, which includes an assessment of the system from source to end-use. The Health Guidelines outline the process for developing a WQMP with an emphasis on system performance targets for reduction of pathogens at critical control points upstream of treatment through to end-use, and verification via operational monitoring (WHO & International Water Association, 2009)[1].

The WQMP considers the full scope of the WRSU system and includes:

a. a project description to characterize the water source(s), end-use, and applicable performance targets (Chapter 2);
b. system design information to ensure hazards in the source water can be removed to the appropriate level (Chapter 3);
c. system commissioning to ensure performance targets are met and management controls are effective (Chapter 4); and
d. system operations that describe monitoring, response procedures, reporting, and maintenance requirements (Chapter 5).

These components are illustrated in Figure 1 and details are provided in the assigned chapters.

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[1] Although there are National and Provincial guidelines that set out end-point water quality values for reclaimed water, those guidelines are limited in scope and do not address multiple alternative water sources and end-uses.

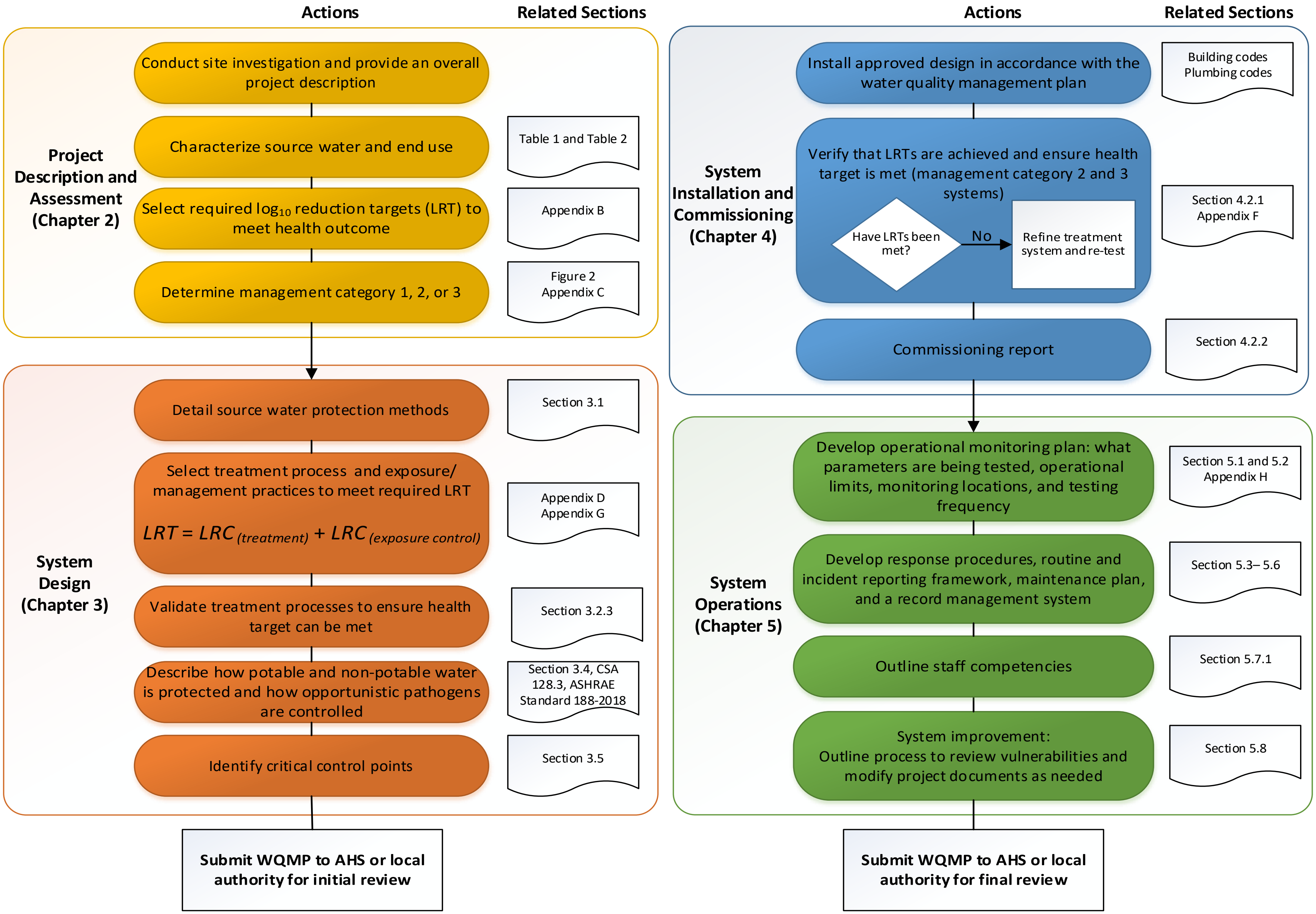

Figure 1. Water quality management plan components

2.0 Project description and assessment

The first component of a WQMP is a detailed project description. The project description should include information to:

a. characterize the source water pathogen (faecal) inputs (section 2.1),
b. characterize the expected product water end-uses (section 2.2),
c. select applicable $\log_{10}$ reduction targets (section 2.3), and
d. determine the management category appropriate for the project (section 2.4).

2.1 Source water characterization

The applicant should provide information to support the classification of the source water into one of the five categories identified in Table 1: municipal wastewater, greywater, stormwater, rooftop collected rainwater, and vehicle wash wastewater. Supporting information includes:

a. A description of the source water. For blended water, the most contaminated source with respect to each human infectious pathogen class (i.e., the source that results in the highest treatment target), which is not necessarily the largest by volume, determines the source water classification.
b. Contributing environmental sources in the surrounding area that could impact the quality or classification of this source water. Sources can include present and past land use, catchment characteristics, and/or historical water quality assessments.
c. Current source water protection measures (section 3.1).

As described in Table 1, there are 5 main categories of source water. Stormwater and greywater both have two sub-categories that are described below.

2.1.1 Municipal wastewater

Municipal wastewater, or sewage, refers to water that is collected on a municipal scale that represents a combination of black water (e.g. toilets and urinal water), greywater (e.g. sinks, showers, laundry), and other wastes from domestic, commercial and industrial sources. In general, this stream of wastewater is the most contaminated with human pathogens and requires the highest $\log_{10}$ reductions when compared to other water sources and the same end-uses.

2.1.2 Greywater

Greywater refers to a stream of domestic wastewater that does not include waste from toilets, urinals, or kitchen sinks and is captured for reuse. Greywater systems are classified into two categories based on the scale of the system:

a. Single family dwelling (e.g., 5-person collection system), and
b. Multi-user buildings(s) (e.g., multi-family dwellings, multi-user commercial buildings, and community systems, such as a 1000-person collection system).

Pathogen inputs and risks to the end-user for greywater collected from single family systems and used by the same people that reside in that home, are different compared to larger scale collected greywater (Jahne et al., 2016). For single family dwelling greywater collection systems, there is a greater variability in pathogen concentrations compared with larger collection systems, but with fewer pathogen types. When greywater is collected from and/or distributed to multiple residences or users in a commercial building or community, there is a greater potential for more types of pathogens to be present and transported to end-users of the water (Sharvelle et al., 2017). The two categories also differ with respect to exposure to pathogens. Levels of exposure in larger system are higher as a result of several factors, such as more users, larger distribution systems, longer retention time of the water in pipes, more interconnections, and a higher likelihood of cross connections. The results of these differences are shown in higher LRTs for multi-family collection systems and greater monitoring and operational requirements as set out by the management category (section 2.4).

2.1.3 Stormwater

Stormwater refers to water collected from rain or snowmelt that flows over land and/or impervious surfaces in developed areas (e.g., streets, parking lots, and rooftops with frequent human access). In general, pathogen concentrations in stormwater can be highly variable; based on experience with stormwater in developed environments, some sewage contamination is likely (Chong et al*.,* 2013; Nshimyimana et al., 2014). Many international studies have demonstrated that stormwater is often contaminated with raw human sewage at levels that range between 0.1% and 10% of the stormwater flows (Li et al., *in prep*; Sharvelle et al., 2017). As such, two levels of contamination have been considered for stormwater sources:

a. 10^{-1} dilution (or 10% contribution from sewage), and
b. 10^{-3} dilution (or 0.1% contribution from sewage).

A 10^{-1} dilution of stormwater with raw human sewage is probable in most developed areas. Human sewage can enter stormwater through sewer overflow into stormwater, illicit cross connections, contamination from animal faecal waste, and leaky sewerage systems (e.g., aging infrastructure) (Sharvelle et al., 2017; Urban Water Resources Research Council et al., 2014). As many of these sources of human faecal contamination will not be detected through a visual sanitary survey, the potential risks should be mitigated through treatment or other management practices.

For the initial assessment, all stormwater sources are assumed to have a 10^{-1} dilution from unintentional raw sewage and should follow the performance targets presented in the appropriate table (Appendix B, Table B-4). If the applicant wishes to use the lower 10^{-3} dilution level of sewage contamination to select the performance target, a third party expert would be required to evaluate the level of human faecal pollution in the stormwater source, which includes monitoring for human faecal *Bacteroides* markers HF183 (most sensitive) and HumM2, or other equivalent sewage markers in the source water during a range of conditions. For a starting point on how to conduct this type of study, please refer to *Pathogens in Urban Stormwater Systems* (Urban Water Resources Research Council et al., 2014) and *Detection of Wastewater Contamination* (Water Environment Federation, 2019). The applicant should contact Alberta Health Services before undertaking an evaluation of this nature.

2.1.4 Rooftop collected rainwater

Rooftop collected rainwater refers to precipitation from rain or snowmelt that is collected directly from a roof surface not subject to public access. LRTs only need to be met for bacteria because human viruses and protozoa are not common in rooftop sources (Sharvelle et al., 2017).

2.1.5 Vehicle wash wastewater

Vehicle wash wastewater is a common water source in Alberta collected from washing of commercial and light vehicles. Throughout Alberta there are several vehicle washes that recycle the generated wastewater for use in subsequent washes after some level of treatment. Although many vehicle washes are privately operated and may only present occupational health and safety risks (section 5.7.2), some may present a public health risk as they are open to the public. For the purpose of the Health Guidelines, vehicle wash wastewater that is generated from domestic or light commercial vehicles (e.g., municipal buses), with little to no animal and/or agricultural transport or exposure, has a similar level of risk as rooftop collected rainwater with respect to microbial hazards. As such, the performance targets that apply to rooftop collected rainwater, also apply to vehicle wash wastewater (see Appendix B, Table B-6). Other types of vehicle wash wastewater should be considered on a case-by-case basis.

2.2 Product water end-use characterization

The WQMP should provide information to characterize the end-use into one of the categories described in Table 2: aesthetic water features, agri-food irrigation, car and truck washing, clothes washing, cooling towers and evaporative condensers, dust control/street cleaning, non agri-food irrigation, recreational, or toilet and urinal flushing.

End-use characterization should include:

a. intended end-use(s) of the reclaimed water,
b. location of water use (e.g., indoors, outdoors),
c. end users (e.g., occupational and/or public exposures),
d. exposure route(s) (e.g., ingestion, inhalation, dermal contact),
e. average number of people exposed to the water per day, and
f. exposure potential (Table 3).

The end-use characterization information should be used to select the performance targets (section 2.3) and determine the management category (section 2.4 and Figure 2). The end-uses have been classified as either low or medium/high exposure based on the potential for human contact through ingestion, inhalation, or dermal contact under normal operation of the intended use (Canadian Standards Association (CSA) and International Code Council, Inc. (ICC), 2018).

Table 3 describes low and medium/high exposures with some example end-uses. Medium and high exposure potentials (which represent direct and indirect exposure) are combined when choosing the management category in Figure 2. Some end-uses can be classified as both low and medium/high exposure potential depending on the exposure controls that are used (section 3.3).

Table 3: Exposure potential for each end-use (CSA & ICC, 2018)

Exposure potential	Description of end-use	End-use
Low	• Rare human contact with the product water • Installation that limits direct or indirect exposure under normal operation • Mainly outdoor applications	• Aesthetic water features (ponds with no direct contact or spray features • Car and truck washing (automatic spraying, drive-through) • Dust control and street cleaning (night time application) • Non agri-food irrigation (spray application with restricted access) • Non agri-food irrigation (subsurface and drip irrigation)
Medium	• Possible indirect exposures • Design incorporates some level of exposure management under normal operation	• Aesthetic water features (fountains, waterfalls) • Agri-food irrigation • Car and truck washing (wand washing) • Clothes washing • Cooling towers and evaporative condensers

High	- Probable direct exposures - No exposure management under normal operation	- Dust control and street cleaning (day time application) - Non agri-food irrigation (spray irrigation with un-restricted access or exposure) - All recreational end-uses (swimming, boating, canoeing, or kayaking) - Toilet and urinal flushing

2.3 Log_{10} reduction target selection

Using the source water and end-use characterizations, the applicant chooses the applicable LRT[2] for the WRSU system. LRTs set the reductions in concentration for each pathogen class (enteric viruses, enteric bacteria, and parasitic protozoa) that are required to meet the health-based targets described in section 1.4. For systems that use a blended source, the most contaminated source water, and not necessarily the largest by volume, should be used to select the performance target (i.e., the water source that results in the largest LRT for each pathogen class).

Appendix B contains the LRTs for each source water and end-use previously described. To find the applicable LRTs, choose the table that corresponds to your source water type. From there, find the appropriate end-use in that table. The LRT values to the right of the end-use are stated for viruses, bacteria, and protozoa, respectively. If the WRSU project has more than one end-use, the end-use that results in the greatest risk to the end-user (i.e., the highest LRT) should determine the performance targets.

2.4 Management category selection

When applying the WSP approach, the system is designed to achieve the LRTs, but just as important is the management of the system to ensure ongoing and consistent delivery of water that meets the health-based target. The applicant should determine the applicable management category (MC) based on the flow diagram presented in Figure 2. The MC sets the applicable technology validation, verification, and monitoring requirements. As the complexity of the system and size of the customer base increases, the level of monitoring and management requirements increases accordingly. The WQMP should incorporate the requirements of the MC for the system.

There are three MCs, which are based on:

a. Population assessment: number of people likely to be exposed to non-potable water;
b. Source water assessment: likelihood that the water supply source is contaminated with human waste and pathogens; and
c. Exposure assessment: proposed use and level of potential exposure (low or medium/high).

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[2] LRTs were derived through quantitative microbial risk assessments (QMRA) that correspond with the probability of infections and establish tolerable risk levels of exposure to pathogens (Sharvelle et al., 2017; WHO, 2016). QMRA accounts for variation in pathogen density over time for each source water, route of exposure, ingested volume, and days of use per year (WHO, 2016). The reference pathogens used for enteric bacteria, viruses, and protozoa are *Campylobacter jejuni*, *Norovirus*, and *Giardia lamblia*, respectively.

A description of each MC is outlined in Appendix C, along with the associated technology validation, verification, and monitoring requirements.

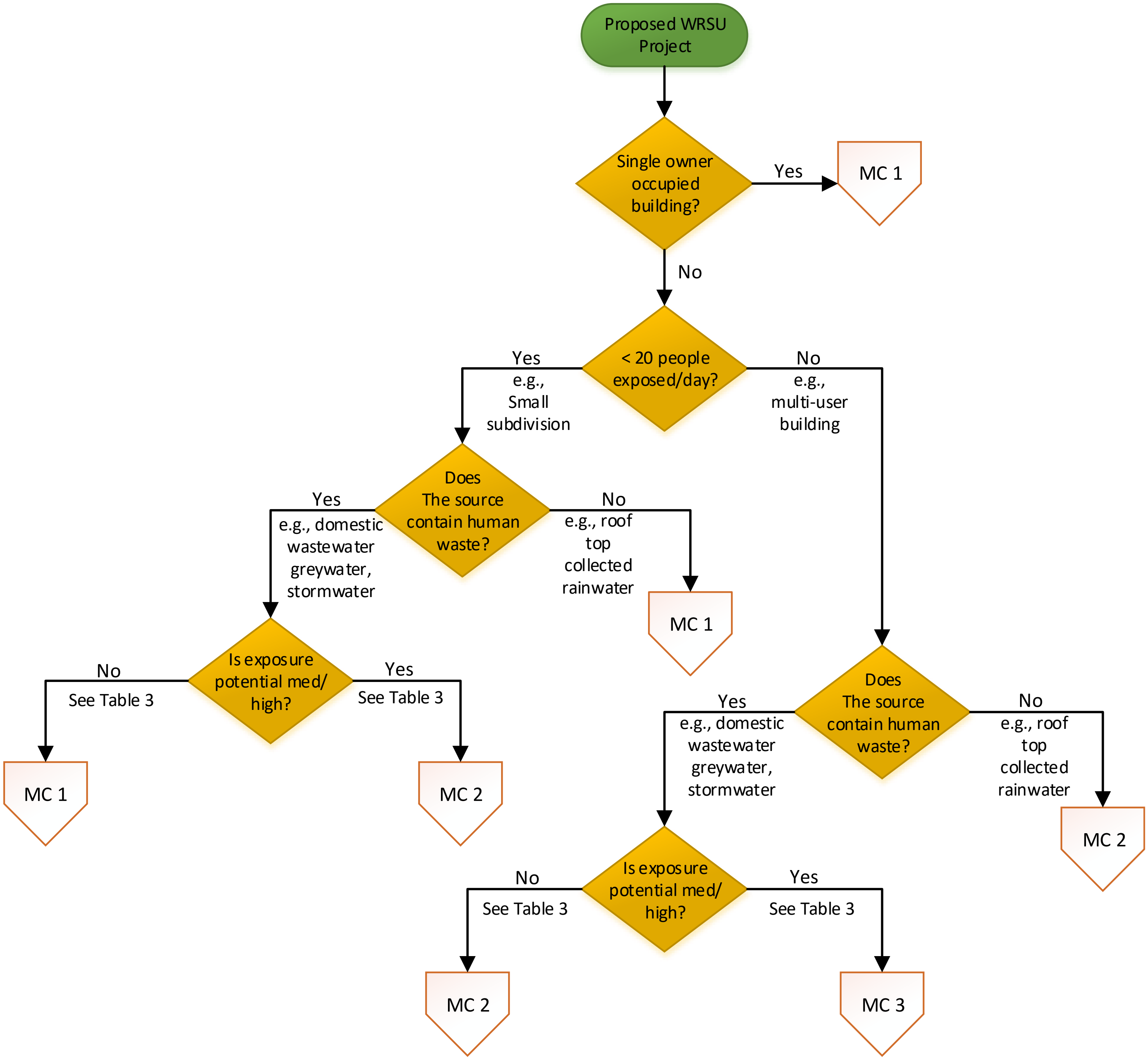

Figure 2: Management category decision tree (Sharvelle et al., 2017)

3.0 System design

This chapter describes the methods to achieve the $\log_{10}$ reductions and maintain water quality throughout the system. The WQMP should provide information on the following aspects of system design, where applicable:

a. Source water protection strategies (section 3.1),
b. Treatment processes (section 3.2 and Appendix D),
c. Exposure controls and management practices (section 3.3 and Appendix G), and
d. Storage and distribution management (section 3.4).

Subsystem design specifications for the WRSU system, such as flows, materials, and sizing, are out of scope of the Health Guidelines and are not needed for the WQMP, but may be needed to meet the needs of the regulator, such as the municipality. All treatment systems should be installed and operated according to the manufacturer's specifications and applicable safety codes requirements.

3.1 Source water protection

Preventing and mitigating hazards from entering the source water is the first barrier against contamination and degradation of the water source. It is prudent to protect the source water where possible to reduce long term operational costs and improve the consistency of the source water quality.

The WQMP should identify the measures that are in place to help protect the source water from additional contamination or deterioration. Some common examples are included in Table 4 for stormwater and rainwater. Although LRCs are not assigned for specific source protection practices, over time, and with rigorous testing and evaluation of the source water and WRSU system, it may be possible to evaluate the improvement in water quality and reduce the required treatment or level of management required to maintain an adequate level of public health protection (i.e., the health-based target).

Table 4: Examples of source water protection methods for stormwater and rainwater

Source Water	Protection Methods
Stormwater	• Cross connection controls and monitoring programs • Managing pesticides • Safely discarding household hazardous wastes • Erosion and sediment control during construction • Street sweeping • Catchbasin cleaning • Drainage covers/grates • Animal Control Bylaws • Conserving and planting natural vegetation including trees • Protecting against human and livestock waste • Reducing spills and impacts of urban, industrial and agricultural discharges • Drainage Bylaws • Aeration
Rooftop collected rainwater	• Controlling hazards in the catchment areas • Regular cleaning of catchment surfaces, gutters, and down pipes • Wire meshes or inlet filters to prevent leaves and other debris from entering • First flush systems to divert contaminated first flow of rainwater

	• Covered storage to prevent mosquito breeding, algal and cyanobacterial growth, and bird/animal droppings • Annual cleaning out of accumulated storage (cistern) sediments

3.2 Treatment processes

To achieve the LRTs and produce water that meets the health-based target, WRSU systems may use treatment options that involve one or a combination of biological, physical, and chemical treatment process units. Treatment options and the associated LRCs are outlined in Appendix D. Performance targets may also be achieved through exposure controls and management practices (section 3.3).

Depending on the MC and complexity of treatment processes, the applicant may consider improving the reliability of treatment processes by incorporating process redundancy, robustness, and resiliency. For example, multiple treatment barriers can be used to create redundancy, so that a reduction in performance in any one process, which possibly translates into an increased risk to the user, is mitigated by other processes in the treatment train. A combination of treatment technologies can provide a more robust treatment approach to address a broad range of constituents and changes in concentrations over time in the source water. System operations, such as monitoring, maintenance, and response plans, can improve the resilience and ability to adapt and restore performance rapidly in the face of treatment failures (Chapter 5). Examples of process design and control features which may be used to enhance the reliability of WRSU treatment systems are outlined in Appendix E. The system design description should include information on what additional process control and design features are used to create a more reliable treatment system. Appendix E also references the three MCs and what processes may be considered to improve treatment reliability.

3.2.1 Treatment process unit selection

Data on treatment process unit effectiveness is available for a myriad of processes that are practical for WRSU projects. For each treatment process unit and microbial category (bacteria, viruses, and protozoa), LRCs have been assigned, which are based on literature or experimental data using secondary treated effluent as the source water (Sharvelle et al., 2017).

The sum of the LRCs from treatment and exposure controls (section 3.3) should meet or exceed the LRT for each microbial category. Appendix E provides LRCs for each treatment process unit within the three main categories (biological, filtration, and disinfection processes). The LRCs provided are intended to help the applicant design an appropriate system and should not be taken as the absolute pathogen reduction level, especially for MC 2 and MC 3 systems that may require the technology to be validated under specific conditions (section 3.2.3). The tables within Appendix E also describe the main operational factors that impact treatment efficacy. Treatment technologies not included in Appendix D may be considered if technology validation is conducted to ensure the treatment process units can achieve the required LRT.

3.2.2 Treatment process unit certification

Although there are some certification standards for non-potable treatment technologies, their performance criteria rely on end-point water quality parameters that are not always health risk-based. For example, NSF International (NSF) *Standard 350: On-site residential and commercial water reuse treatment systems* (NSF & American National Standards Institute (ANSI), 2016) and Canadian Standards Association (CSA) *B128.3-12: Performance of non-potable water reuse systems* (CSA, 2012) both describe a water treatment system certification process that establishes minimum conventional water quality parameters (e.g., biological oxygen demand (BOD), total suspended solids (TSS), faecal coliforms, pH), but do not specify pathogen reductions or health-based targets.

Since CSA B128.3-12 (CSA, 2012) and NSF 350 (NSF & ANSI, 2016) are some of the only existing resources that are available for guidance, some provinces have adopted one of these water quality standards for use in their water reuse programs. Examples include the *National Plumbing Code of Canada* (National Research Council Canada & Canadian Commission on Building and Fire Codes, 2015), which is anticipated to adopt water quality parameters from CSA B128.3-12 and the health-based targets from CSA B805-18/ICC 805-2018. It is up to the authority having jurisdiction (AHJ) to decide if and when they would require certified equipment or apply and enforce any end-point water quality standards (AMA, 2017).

3.2.3 Technology validation

The LRCs assigned to each treatment process unit in Appendix D can vary based on the source water quality or feedwater quality parameters such as turbidity, BOD, and TSS. Technology validation may be needed to ensure treatment process units can meet the performance target allocated to that technology for the expected range of water quality. Validation testing is recommended for MC 2 systems and essential for MC 3 systems. Appendix F outlines when validation should be undertaken. All analyses should be conducted by an accredited laboratory.

The *Guidelines for Validating Treatment Processes for Pathogen Reduction: Supporting Class A Recycled Water Schemes in Victoria* (State of Victoria, 2013) provide detailed information on treatment validation. The methods outlined in the *Guidelines for Validating Treatment Processes* are an acceptable approach to treatment validation for non-potable treatment technologies in Alberta.[3] When required, the WQMP should outline the validation plan and test results.

Pre-validated systems

Some equipment, such as membranes and ultraviolet (UV) units can be purchased ‘pre-validated’. This means the design has been independently tested for a specific range of conditions to meet requirements. If pre-validated units are used in the system design, further validation is not required. However, these units should be operated within the range of conditions that the unit was validated under. The range of acceptable conditions should be included as part of verification and operational monitoring (sections 4.1/5.2 and 5.1).

Independent third-party oversight

Validation testing should be undertaken by an independent third-party to ensure that the study is conducted in a technically sound and unbiased manner. This has the benefit of expertise and timely analysis of data, as well as ensuring the validation report contains accurate data and results. An independent third-party is a person or agency with no real or perceived conflict of interest regarding the WRSU project or the ultimate use of the treatment process unit being tested (State of Victoria, 2013). An independent third-party may be a testing organization, a municipality, a manufacturer, or a research body. The person or agency should have experience in validation testing (i.e. microbial surrogates) and process control and instrumentation, where applicable.

Prior to reclaimed water being supplied to customers, the applicant should provide written confirmation from the independent third-party stating that they do not have a real or perceived conflict of interest

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[3] Although bacteria may be more abundant in raw sewage, protozoan parasites and enteric viruses are more significant in recycled water schemes due to their relatively high infectivity and resistance to most treatment process units. Therefore, viruses and protozoan parasites represent the target pathogen groups for validation (State of Victoria, 2013).

regarding the WRSU project or the ultimate use of the treatment process unit being tested. This written confirmation should be included in the WQMP.

Validation process and outcomes

Validation can begin in the system design phase as a desktop exercise. For example, validation could include the calculation of the required contact time for a chemical disinfectant based on the physical design of the treatment system. Pilot studies in a laboratory or test setting can also be used for validation. If this is not possible, another option may be to assign preliminary LRCs to a treatment process and then conduct in situ validation. The preliminary LRCs can be based on:

a. the LRCs presented in Appendix D;
b. the results of similar unit operations;
c. existing technology installations;
d. modeling studies, and/or
e. bench or pilot testing.

Each treatment process unit should be validated, as opposed to the entire treatment train being validated as one unit. For pathogen removal validation, challenge testing is conducted with surrogates (organisms[4], particulates, or chemicals) over a defined range of operating conditions. For a surrogate to be suitable it should be either:

a. reduced (removed or inactivated) by the treatment process unit to an equivalent or lesser extent than the target pathogen, or
b. possible to demonstrate a reproducible correlation from literature, laboratory, or field trials between reduction of the surrogate and the target pathogen (Sharvelle et al., 2017).

In some cases, indigenous organisms from the water source, mainly *E. coli* and *Enterococcus* spp., can be used for validation if present in consistently high concentrations.

For validation testing to be successful, an understanding of pathogen reduction mechanisms, the factors that affect the efficacy of the treatment process unit, and the relevant operational monitoring parameters (indicators of treatment efficacy), are required. A validation plan should include details of the challenge test, surrogates to be used, parameters to be monitored, sampling program, and quality control measures. The study should be planned and conducted by qualified personnel using appropriate analytical techniques, an accredited laboratory for testing, calibrated equipment, and including appropriate documentation.

The two main outcomes of validation testing include:

a. Monitoring strategy: The validation testing should help inform the parameters, critical limits, and locations for monitoring.

b. Log_{10} reduction value (LRV): An essential goal of the validation study is to collect representative data that can be used to form a statistical basis for the $\log_{10}$ reduction values. The validation testing should determine the LRV for each pathogen class and treatment process unit within the defined critical limits. The LRV should be summed for each unit process to determine if the LRT for the source water and end use can be met.

Validation report

A validation report that summarizes the validation process and results should be included in the WQMP. The report should be developed by an independent third party. Details on the validation report are provided in the *Guidelines for Validating Treatment Processes for Pathogen Reduction* (State of Victoria, 2013).

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[4] When using pathogenic surrogates that fall into Risk Groups 2, 3, or 4 for performance validation, a license, issued by the Public Health Agency of Canada, is required under the *Human Pathogens and Toxins Act* (Government of Canada, 2018).

Re-validation

Re-validation should occur following any major change within the WRSU system for both MC 2 and MC 3 systems. Changes that may trigger re-validation include:

a. the introduction of new processes or equipment,
b. changes to the source water or product water quality,
c. identification of new or emerging hazards,
d. repeated systemic failures,
e. catchment inputs increasing beyond the maximum flow tested during validation,
f. variation in process configuration, operational parameters or mode of operation,
g. new membrane specification,
h. new chemical used in treatment processes, and
i. any unscheduled suspension to supply or operation.

3.3 Exposure controls and management practices

The WQMP should outline the exposure management practices that should reduce exposure of end-users to the water, where applicable. There are some exposure controls and management practices that have been assigned a LRC, similar to the treatment processes. The LRCs can be used to fully or partially meet the required LRTs for each combination of source water and end-use.

$$LRT \leq LRV + LRC_{exposure\ controls}$$

Exposure controls and management practices, and their associated LRCs are outlined in Appendix G and include:

a. food processing,
b. controlling methods of application and application rates,
c. setting withholding periods, and
d. controlling public access and application times.

Where exposure controls are applied, the WQMP should outline how the exposure control is monitored during operation (section 5.1).

Accidental exposure can also be reduced through the use of other management practices such as:

a. signage indicating that reclaimed water is being used and it is not suitable for drinking,
b. labelling of infrastructure such as valves and piping, indicating that they are being used to distribute reclaimed water, and
c. communication to users that provides advice on appropriate and inappropriate uses of reclaimed water.

3.4 Storage and distribution

In addition to adequate treatment of the source water to control enteric pathogens, it is also necessary to manage the storage and distribution aspects of the WRSU system from source to the point of human exposure. The water should be protected throughout the storage and distribution components, whether located before or after treatment, to prevent contaminating or compromising the operation of the WRSU system. The WQMP should outline the storage and distribution system components and how they are maintained to protect the quality of the reclaimed water.

The storage capacity should be adequate to meet the demands of the system and have back-up storage to accommodate weather variation and/or process upsets, where applicable. For example, water may need to be released when storage capacity is exceeded by increased inflows due to climate/weather variability (especially seasonally), or other sources of variability in source water.

All storage and distribution components (e.g., piping/equipment) should be made from materials that are compatible with the water source (e.g., minimize or eliminate chemical reactions, corrosion, etc.). All storage and distribution components should be protected from external contamination or damage, where possible, such as:

a. entrance of insects and vermin into storage tanks or access by livestock/wildlife (including birds),
b. chemical pollution from nearby transportation corridors, airports, etc.,
c. nearby or upstream sources of human pollution (e.g., wastewater treatment plant, reuse projects, landfills, etc.),
d. nearby or upstream industrial activities (including mining, forestry, etc.),
e. light that may cause cyanobacterial growth,
f. physical damage (e.g., traffic, tampering, or vandalism),
g. debris accumulation and/or clogging, etc. due to low flow or inadequate flushing practices, and
h. heavy rainfall, natural disaster, etc. causing sediment build up, debris entrainment, erosion, etc.

3.4.1 Protection of potable water

In some designs, the WRSU system may be connected or run in parallel to the existing potable water sources and plumbing system. The WQMP should describe how potable water is protected. Systems should be designed, installed, maintained, and monitored to prevent contamination of any potable water supplies and distribution piping, and should comply with the *National Plumbing Code of Canada* (NRCC & CCBFC, 2015) and local requirements of the AHJ. The three main strategies for protecting potable water supply protection are cross connection control, backflow prevention, and non-potable system identification.

Cross connection control

Prevention of cross connections is an important mechanism for preventing contamination of high-quality waters, including distribution systems and sources of drinking water. Potential cross connections can occur where potable water is used to supplement/augment the WRSU source.

The WQMP should outline measures to prevent cross connections with potable water and non-potable water supplies. CSA B128.1-06 provides guidance on water supplier cross connection control programs (CSA, 2006). One example is to perform cross connection tests to physically verify that the potable and non-potable water systems are separated, preferably via an air gap. The AHJ can further advise on local cross connection control programs and testing for specific jurisdictions.

Backflow prevention

A non-potable water supply should not be connected with the potable water supply, but a potable water supply may be connected to a non-potable water system with appropriate backflow protection, as required by the *National Plumbing Code of Canada* (NRCC & CCBFC, 2015) or the 2014 *Alberta Building Code* (NRCC, 2014). Backflow prevention can be accomplished via an air gap or a backflow preventer.

Although backflow preventers are recognized as devices to safeguard water systems, some backflow preventers have a tendency to fail and are ineffective in protecting a potable water system from opportunistic pathogens that develop in a static or closed system. Microbiological agents, when given the right conditions, will develop into a microfilm and colonize the water system, particularly under conditions of low flow and moderate temperatures. Backflow prevention devices, such as a double check valve assembly (DCVA) or reduced pressure (RP) principle back flow prevention device, require annual testing and are more effective in minimizing failures. There are also strategies to improve efficacy such as ensuring positive pressure differential in the direction from potable to non-potable application (e.g., closed fire sprinkler system vs a fire system that serves one water closet).

The AHJs discourage the use of backflow preventers for protection of the potable water supply against microbial risk and recommend using an air gap as the best protection. Air gaps are more effective at water supply protection, and are low cost and low maintenance. It is the decision of the AHJ to determine if backflow preventers can be utilized for WRSU systems.

Non-potable system identification

Identification of non-potable system components can also be used to protect potable water, as well as the non-potable product water. Identification can be accomplished by installing signage, valve tags, and purple pipe or other appropriate pipe identification schemes. Further information on system identification can be obtained through the AHJ.

3.4.2 Management of opportunistic pathogens

The WQMP should address how opportunistic pathogens will be controlled in the storage and distribution systems, where applicable. The growth of opportunistic pathogens, such as *Legionella pneumophila, Pseudomonas aeruginosa*, and *Mycobacterium avian* (non-tuberculosis mycobacteria), can occur post-treatment in storage and distribution components of WRSU systems (Dowdell et al., 2019; Schoen & Ashbolt, 2011). These water-based pathogens are able to proliferate within biofilms in stagnant or low flow piped water with moderate temperatures, leading to the potential for exposure to pathogens at end-uses where inhalation of aerosols and product water are possible routes of exposure. WRSU projects present a higher risk of opportunistic pathogen growth compared to potable water mainly due to warmer temperatures, elevated levels of biodegradable organic carbon and other nutrients, lower disinfectant residuals, and variable use patterns that lead to stagnation and depressurization, among others (Jjemba et al., 2015).

The following criteria can be used to determine whether a WRSU system presents a potential risk for *Legionella* spp. or other opportunistic pathogen growth and requires prevention and control (National Academies of Sciences, Engineering, and Medicine (NASEM), 2020):

a. presence of *Legionella* in the system water,
b. water temperature between 25°C to 45°C,
c. means to create and/or spread aerosols,
d. system stores and/or re-circulates water, or
e. systems contains a source of nutrients (e.g., sludge, rust, scale, organic matter, or biofilm).

For some end-uses, like cooling tower water, car wash water, and water for fire suppression, opportunistic pathogens are most effectively managed in the storage and distribution system. Table 5 summarizes the recommended management practices for the prevention and control of opportunistic pathogens.

Table 5: Recommended practices for the prevention and control of opportunistic pathogens (ANSI/ASHRAE, 2018; NASEM, 2020; Sharvelle et al., 2017)

Recommended Practice	Considerations
Disinfection	• In general, a higher disinfectant residual will reduce pathogen regrowth potential. • The choice of disinfectant will depend on the overall system design. • The recommended disinfectant residuals are: 1. ≥ 0.20 mg/L and ≤ 4.0 mg/L for free chlorine 2. ≥ 0.50 mg/L and ≤ 4.0 mg/L for chloramine 3. ≥ 0.20 mg/L and ≤ 0.80 mg/L for chlorine dioxide • Different disinfectants offer advantages and disadvantages to overall water quality and system management. It is critical to understand any potential disinfectant byproducts or other reactions that may occur. • Disinfectant booster stations can be used within the distribution system to ensure adequate disinfectant residuals for systems with long retention times. • Chloramine provides a better residual duration as compared to chlorine. • When the chlorine-to-ammonia ratio (4.5:1) is not properly managed in chloraminated water, nitrification can occur, enhancing biofilm biomass and increasing the number of protozoan hosts for opportunistic pathogens. • Various combinations of UV, chlorine, chloramine, ozone, and hydrogen peroxide are beneficial for specific disinfection goals.
Nutrient Limitation	• The primary energy source for pathogen regrowth is organic carbon measured as available organic carbon, biodegradable dissolved organic carbon, or total organic carbon. • Essential nutrients for pathogen regrowth include nitrogen (N), phosphorous (P), and iron (Fe). • Product water that is low in carbonaceous material and nutrient content (e.g., low levels of available organic carbon, total organic carbon) will help prevent regrowth post treatment.
Plumbing materials	• Use non-reactive, biologically stable construction materials, like copper or polypropylene.
Temperature control	• Maintain water temperature at less than 20°C or greater than 55°C for hot-water applications (i.e., avoid the storage and distribution of non-potable water within 20°C to 55°C). • Store water in-ground at a temperature below 20°C.
Hydraulic management	• Cleaning and maintaining storage tanks and flushing the distribution system will aid in reducing re-growth potential. • Reducing areas of stagnation (dead zones, prolonged periods of zero-flow or low flow, inadequate mixing) through system redesign (e.g., looped pipes) or flushing programs will help maintain disinfectant residuals and reduce sediment deposition, reducing re-growth potential.

	• The frequency of storage tank cleaning required varies depending upon the quality of water stored, retention time in storage, temperature of the water, and nature of the tank. Tanks that are open to the atmosphere require more frequent cleaning. • The frequency of distribution system flushing required varies depending upon the quality of water transmitted, retention time in the distribution system, temperature of the water, and nature of the distribution system components. Periodic flushing is a good means of both removing sediments and scouring pipe walls. System design should include means for easily flushing pipes as part of routine maintenance.
Exposure controls	• Limit aerosolization of product water. • Examples include: - drift eliminators for cooling towers and evaporative condensers, - drip irrigation application instead of spray irrigation, and - laminar flow for showers, faucets aerators, and spray nozzles.

3.5 Identification of critical control points

Critical control points (CCPs) are locations in the system, including management and treatment processes, which have a direct impact on the quality of reclaimed water (i.e., pathogen management). The WQMP should identify the CCPs, either through a simple schematic or narrative. Management and treatment processes are considered a CPP if they meet the following criteria:

a. designed specifically to substantially reduce the risk presented by the microbiological hazard, including opportunistic pathogens;
b. can be monitored and corrected in a timely fashion; and
c. failure would lead to immediate corrective action or cessation of the supply.

CCP information should be used to develop the verification (section 4.2.1) and operational monitoring (section 5.1) components of the WQMP.

3.6 Initial submission for review

Following completion of the project description and system design for the WRSU project, it is recommended that the applicant submit the WQMP to the appropriate stakeholder for initial review prior to constructing or commissioning the WRSU system. Please refer to the Water Reuse and Stormwater Use website for more information.

The review should help to verify that:

a. the source water has been properly classified and the most contaminated water source is used to determine the required LRTs,
b. the end-use has been properly classified to include the highest exposure potential,
c. the sum of the LRCs (or LRVs for validated technology) for the proposed treatment and exposure controls meets or exceeds the required LRTs for enteric viruses, bacteria, and protozoans for the specified source water and end-use, and
d. there is an appropriate plan in place for protection of the potable water supply and control of opportunistic pathogens.

4.0 System installation and commissioning

After the preliminary WQMP has been reviewed and necessary approvals received, the next step is installing the system.[5] Some important reminders about installation are outlined below, along with system commissioning information and requirements for the WQMP.

4.1 System installation

The design and installation of the WRSU treatment plant should:

a. be consistent with the WQMP,
b. ensure CCPs and associated control limits are effective, and
c. prevent off-specification water from entering the supply system.

Where applicable, the design and installation of the WRSU system should allow operational personnel to monitor and control the process reliably, accurately, and in a timely manner. This may mean the incorporation of sampling ports at critical control points, or access to areas that need regular maintenance.

4.2 Commissioning

System commissioning is the process of assuring the components of the WRSU system are designed, installed, tested, operated, and maintained to protect public health. A commissioning process may be applied not only to new projects but also to existing systems that have undergone improvements, upgrades, other changes, or during seasonal start-up. During the commissioning phase, product water should be discharged. A commissioning plan describing the manner in which the plant and equipment should be tested and the acceptability criteria should be developed.

For systems in MC 2 and MC 3, the applicant should provide an outline of the commissioning process, conduct the commissioning of the system including commissioning verification (section 4.2.1), document the results in commissioning report (section 4.2.2), and adjust the operations and monitoring components (Chapter 5) accordingly. Systems in MC 1 do not need to conduct a commissioning process.

4.2.1 Commissioning verification

In addition to technology validation, verification of the entire treatment train should be conducted to confirm that the specific controls produced water that was safe for the intended end-use during the commissioning phase (Appendix F). Verification is essential during commissioning or re-commissioning of MC 3 systems and recommended for MC 2 systems (Appendix C). Verification monitoring involves end-point monitoring of water quality and can include indigenous organisms, like *E. coli,* or their surrogates, as well as conventional water quality parameters. All analyses should be conducted by an accredited laboratory.

Depending on the type and complexity of the treatment process unit, assessment of the full system performance through commissioning verification can only be evaluated once a pseudo-steady state is reached, which may require several months of operation. The additional time to reach a steady state should be incorporated into planning for the commissioning of the system. More detailed information on verification monitoring can be found in section 5.2.

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[5] A WQMP should also be developed for systems that are currently in operation.

4.2.2 Commissioning report

A commissioning report should be included as part of the WQMP and should identify, where applicable:

a. the methods (hydraulic and contaminant load) and results of the commissioning verification,
b. location and schedule for all sampling or measurements,
c. methods used to analyze samples or make measurements,
d. situations that resulted in out-of-specification performance,
e. actions taken to correct water quality exceedances,
f. testing of shutdown and/or diversion systems, and
g. testing results of alarm systems.

5.0 System operations

The WRSU system should be operated, maintained, and monitored in order to meet the performance targets for the system. From a health perspective, the most important aspects of the system operations are to develop and implement monitoring, reporting, and maintenance plans.

5.1 Operational monitoring plan

The WQMP should include an operational monitoring plan for projects within MC 2 and MC 3. The operational monitoring plan should detail what parameters are being monitored, operational limits for each selected parameter, along with the monitoring locations and frequency. The monitoring plan should reflect what was demonstrated during the technology validation and commissioning phases, where applicable.

5.1.1 Locations

The operational monitoring plan should clearly outline where each parameter is being monitored. The CCPs identified in section 3.5 should be used for the monitoring locations for the treatment train. Monitoring locations can also include the exposure controls, and in some cases, the surrounding environment.

5.1.2 Parameters

Monitoring parameters should be determined based on what types of treatment, exposure controls, and management systems are in place to achieve the required LRTs. Appendix H describes some recommended monitoring parameters and surrogates for each treatment process unit. For off-the-shelf technologies, the manufacturer’s specifications may also give information on what parameters should be monitored to ensure treatment effectiveness.

5.1.3 Critical limits

The critical limits for each of the selected parameters also need to be established. Appendix H lists examples of parameters for each treatment process unit, but does not give information on operational limits (i.e., acceptable values or ranges for each parameter), as this information would be set on a case-by-case basis according to the manufacturer’s specifications or what was found during validation and commissioning phases. Procedures that outline how to respond to operational limit exceedances (i.e., system upsets) also need to be developed (section 5.4).

5.1.4 Frequencies

For each parameter and location, the operational monitoring plan should outline how often monitoring is taking place. Some parameters can be monitored continuously using an online system (e.g., sensors) for real time observations. All proposed monitoring equipment should be installed during the construction phase, as many will be online or integrated into other components of the treatment system.

Where parameters cannot be monitored continuously, the operational monitoring plan should detail how often each location would be monitored (e.g., daily, weekly, and monthly). For variables that cannot be measured using an online system, grab samples may have to be used.

5.2 Verification monitoring plan

The WQMP should detail the parameters, critical limits, and frequencies that relate to the verification of the full treatment system. Verification monitoring is endpoint monitoring and is undertaken routinely to assess whether the treatment train and management controls have worked. Historically, verification monitoring was used to indicate treatment efficacy and show that water delivered to the customer was safe. While it should not be relied upon solely as an indicator of reclaimed water treatment processes efficiency, periodic verification monitoring is still recommended to complete the monitoring feedback loop (State of Victoria, 2013). Verification monitoring involves end-point testing of water quality for faecal indicators, such as faecal indicator organisms, like *E. coli,* or their surrogates (e.g., chemical microbiological, and particles). All analysis should be conducted by an accredited laboratory.

The verification monitoring plan will differ for each end-use. For some end-uses, detection of faecal indicators or surrogates is likely to indicate system failure or contamination (State of Victoria, 2013). For other end-uses, like recreational uses, established health guidelines can be used to develop the verification monitoring plan. The *Alberta Safe Beach Protocol* (Alberta Health, 2019) is one such guideline that has established statistical threshold values for *Enterococcus* spp. that can be monitored at the point of use. The *Protocol* was developed using the one in 100 voluntary infection risk for recreational waters (Schoen et al., 2017; US EPA, 2012b).

5.3 Maintenance plan

The WQMP should also include details on how the system is being maintained. A maintenance plan is necessary to document how the full system is maintained and to build consistency and continuity of operation. This plan could include:

a. a maintenance schedule (dates and times of routine inspections and repairs),
b. details on how the system needs to be started and shut-down during times of maintenance or emergency,
c. an outline of how to ensure a sufficient water supply (e.g., controlling evaporation and sediment deposition in storage bodies and/or surface water),
d. equipment inspection checklists,
e. verification of controls being in place and effective (e.g., alarms),
f. new hazards identified,
g. how to manage over-supply and/or loss of containment of water, and
h. an outline of how to switch to potable water or secondary supply where an outage occurs and a water supply is essential.

The full maintenance plan would likely be a stand-alone document that can be referenced in the WQMP.

5.4 Response procedures

The operational monitoring, verification monitoring, and maintenance plans should adequately monitor and maintain the treatment process such that any discrepancy, equipment reliability issue or unacceptable variability in the reclaimed water quality is readily identified and effectively rectified. For each of the operational limits set out in the operational and verification monitoring plans, procedures that outline corrective actions to exceedances of the limits (i.e., system upsets) also need to be incorporated into the WQMP. Response procedures may include, but are not limited to:

a. system shut down,
b. provision of alternative sources,
c. specific responses for individual process unit failures, and

d. disposal of inadequately treated water.

Developing response procedures should involve assessing what effect the exceedance(s) or incident(s) have on public health, the environment, and the overall operation of the system. Recall that for systems having process resiliency, robustness, and redundancy (i.e., multiple barrier approach) incorporated into the design, a short-term system upset will likely not significantly affect the infection risk to the public (Appendix F).

5.5 Routine and incident reporting

A reporting process is another component of the system operations. The reporting process should set a schedule and framework for providing ongoing documentation certifying that public health is being protected. The WQMP should include a reporting plan that outlines what needs to be reported, who it needs to be reported to, and when it should be reported.

Routine reports should include all information necessary for determining compliance with the appropriate requirements depending on the type of project, including:

a. operational monitoring results,
b. cross connection tests and inspections,
c. significant maintenance activities,
d. treatment modifications,
e. operational limit exceedances and actions,
f. failed verification monitoring, and
g. outages (including reasons and durations).

In addition to routine reporting, other incidents that may indicate a risk to the public (e.g., suspected cross connections, treatment bypasses, or reports of illness) should be reported immediately to the appropriate regulator or stakeholder. The regulator(s) should also be notified when any significant changes are made to the project over the course of its design, implementation, and operation.

5.6 Records management

Another component of the WQMP is records management. Methods of documentation could include manual and electronic record keeping and documentation using data logging and preservation (e.g., training programs, monitoring data, incident reporting). A process for reporting data and information should include the method and frequency of reporting summary reports to the regulator, preferably in electronic format.

5.7 Additional management practices

5.7.1 Staff competencies

To support the optimal operation of the system, systems should be overseen and operated by staff who are knowledgeable about the operations and technology of the system. It is important for operational staff to understand the system and risks so they can make effective operational decisions and be aware of the potential consequences of system upsets. Including staff competencies in the WQMP is recommended for MC 2 systems and MC 3 systems. This documentation could include:

a. a training manual or other documentation, and

b. certification[6] and/or qualifications and experience of those who are responsible for managing and maintaining the WRSU system (e.g., operators, contractors, designers and administrators).

5.7.2 Occupational exposures

The Alberta *Occupational Health and Safety Act* (S.A. 2017, c. O-2.1), regulations, and Code apply to all provincially regulated employers and workers in Alberta. The employer must protect the health and safety of workers on their work site and the design and construction of all components of the WRSU system shall conform to the safety provisions of the relevant legislation. For more information on occupational exposure, please refer to https://www.alberta.ca/occupational-health-safety.aspx.

5.8 System improvement

The final component of the WQMP is to establish a process for system improvement. This process can include continuous and methodical review of the vulnerabilities, evaluation of system performance, and modification the system through improvements where needed. It is the responsibility of the applicant to implement these solutions at the operational level and to modify the appropriate project documents as required. To document this continual improvement process, it is helpful to produce an annual report to summarize the system's performance, and to provide updates to the WQMP, including identification of new hazards and upgrading or changing procedures in response to new hazards.

5.9 Final submission for review

Following system commissioning and development of a commissioning report, along with development of a monitoring and reporting plan, it is recommended that the applicant submit the full WQMP to the appropriate regulator (e.g., AHJ) for review. The review would help to verify, where applicable:

a. results of the verification testing;
b. completeness and appropriateness of the monitoring plan, including monitoring parameters, thresholds for each parameter, monitoring locations, and frequencies;
c. an outline of the upset conditions and thresholds that initiate incident and emergency protocols and a description of the response;
d. documentation including manual and electronic record keeping and data logging and preservation (e.g., training programs, monitoring data, incident reporting); and
e. the reporting process for non-compliant results and/or exceedance of performance thresholds.

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[6] At the time of writing the Health Guidelines, there were no specific certifications for operating water reuse and stormwater use systems. Some jurisdictions are exploring training programs or adding additional education to existing certifications related to drinking water and wastewater treatment.

Appendix A: Annual infection risk and exposure considerations for each end-use

The Health Guidelines use annual infection risk as the health benchmark unit to form the basis of performance targets. The two health benchmarks are:

1. $1x10^{-2}$ infection risk (i.e., 1 infection per 100 exposed persons per year)
   This infection risk is based on the same infection risk that is acceptable for recreational water exposure. End-uses that fall into this category are usually outdoor (lower exposure potential) and are sometimes voluntary (higher acceptable risk).

2. $1x10^{-4}$ infection risk (i.e., 1 infection per 10,000 exposed persons per year)
   This infection risk is based on the same infection risk that is acceptable for potable water exposure. End-uses that fall into this category are usually indoors (higher exposure potential) and are considered involuntary (lower acceptable risk).

Table A-1: End-uses and their associated health benchmark

End-use	Benchmark (infection risk)	Exposure considerations and references
Aesthetic water features	$1x10^{-2}$ Outdoor water feature $1x10^{-4}$ Indoor water feature	Exposure information based on Li et al., *in prep*. The main routes of exposure are inhalation of aerosols and hand-to-mouth contact. Estimated volume of ingestion is $1x10^{-3}$ L, approximately 17 times per year.
Agri-food irrigation[a]	$1x10^{-4}$	Likelihood of illness is greater with food for raw consumption. Exposure information based on NRMMC et al. (2006). The main routes of exposure are ingestion of raw food and inhalation of aerosols (4 months in Alberta).[a] Raw food consumption considered leafy vegetables, like lettuce (more water uptake), and other produce, such as tomatoes and carrots.
Car and truck washing	$1x10^{-4}$	Exposure information based on Sinclair et al., 2016. The main route of exposure is inhalation of sprays. High pressure hand-sprays, 10 minutes of exposure, 20 times per year.
Clothes washing [b]	$1x10^{-4}$	Exposure information based on NRMMC et al. (2006). The main route of exposure is hand to mouth ingestion. Estimated volume of ingestion is $1x10^{-5}$ L twice (two loads) per week, or 104 times per year.
Cooling towers and evaporative condensers [c]	$1x10^{-2}$	Exposure information based on Li et al., *in prep*. The main route of exposure is inhalation of aerosols. Estimated volume of ingestion is $5x10^{-3}$ L per year, approximately 30 days per year.
Dust control/street cleaning	$1x10^{-2}$	Exposure information based on NRMMC et al. (2006). The main route of exposure is indirect ingestion via contact with washed lawns and surfaces.

		Estimated volume of ingestion is $1x10^{-3}$ L per day, for 52 days per year (or once per week).
Non agri-food irrigation	$1x10^{-2}$	Exposure information based on NRMMC et al. (2006). The main route of exposure is inhalation of aerosols. Ingested volume estimated 1×10^{-3} L per day, up to 60 days per year.
Recreational	$1x10^{-2}$	Exposure factors from ingestion based on Dorevitch et al. (2011) and Schoen & Ashbolt (2010). The main route of exposure is ingestion of water. Estimated volume of ingestion is $3.9x10^{-3}$ L per day, 13 days per year.
Toilet and urinal flushing	$1x10^{-4}$	Exposure information based on NRMMC et al. (2006). The main route of exposure is inhalation of aerosols. Ingested volume estimated 1×10^{-5} L per use and 5 uses per day for 365 days per year.

[a] For foods and crops that are further processed, log reduction credits can be applied to meet the log reduction target (Appendix G).

[b] Note that most pathogen contamination is due to soiled clothing and not the source water used to wash clothes, and hence the risk is not significantly different from when potable water is used (Sharvelle et al., 2017).

[c] The risk associated with post treatment opportunistic pathogens needs to be further addressed through management controls. Refer to section 3.4.2.

Appendix B: Log$_{10}$ reduction target summary tables

A probabilistic quantitative microbial risk assessment (QMRA) was used to derive the pathogen log$_{10}$ reduction targets (LRTs) that correspond with tolerable risk levels (1x10^{-2} and 1x10^{-4}) for exposure to pathogens per person per year (Haas, Rose and Gerba, 1999; Li et al., *in prep;* Schoen et al., 2017; WHO, 2016). The LRTs are a minimum value that are to be achieved through treatment and/or exposure management controls.

Water-borne pathogens such as *Legionella pneumophilia*, may grow post-treatment and should be addressed using best management practices as outlined in section 3.4.2.

Table B-1: Log$_{10}$ reduction targets for untreated municipal wastewater[a]

Water End Use		Log$_{10}$ Reduction Target for Viruses[b]	Log$_{10}$ Reduction Target for Protozoa[b]	Log$_{10}$ Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	6.0	5.0	5.5
	Outdoor	4.0	3.0	3.5
Agri-food irrigation [c]		7.0	6.5	7.0
Car/truck washing		5.5	4.5	5.5
Clothes washing		4.5	3.5	4.5
Cooling towers and evaporative condensers		4.5	4.0	4.5
Dust control/street cleaning		3.5	2.5	3.5
Non agri-food irrigation		3.5	2.5	3.5
Recreational		4.0	3.5	4.0
Toilet and urinal flushing		5.5	5.0	5.5

[a] Log$_{10}$ reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log$_{10}$ reduction credits are available to meet the LRT through food processing (Appendix G).

Table B-2: Log_{10} reduction targets for greywater from a single family residential system[a]

Water End Use		Log_{10} Reduction Target for Viruses[b]	Log_{10} Reduction Target for Protozoa[b]	Log_{10} Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	4.0	0[d]	0[d]
	Outdoor	2.0	0	0
Agri-food irrigation[c]		6.5	0	0
Car/truck washing		4.5	0	0
Clothes washing		3.5	0	0
Cooling towers and evaporative condensers		3.0	0	0
Dust control/street cleaning		1.5	0	0
Non agri-food irrigation		1.5	0	0
Recreational		2.5	0	0
Toilet and urinal flushing		5.0	0	0

[a] Log_{10} reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log_{10}reduction credits are available to meet the LRT through food processing (Appendix G).

[d] LRTs for protozoa and bacteria are zero because the likelihood of greywater being a significant source of these pathogen classes is very low compared to other exposure pathways. Therefore, any log reduction would not change the risk for these two via greywater.

Table B-3: Log_{10} reduction targets for greywater (from a community system)[a]

Water End Use		Log_{10} Reduction Target for Viruses[b]	Log_{10} Reduction Target for Protozoa[b]	Log_{10} Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	5.0	3.0	3.0
	Outdoor	3.0	1.0	1.0
Agri-food irrigation[c]		6.5	4.5	4.5
Car/truck washing		5.0	2.5	3.0
Clothes washing		4.0	2.0	2.0
Cooling towers and evaporative condensers		4.0	2.0	2.0
Dust control/street cleaning		3.0	0.5	0.5
Non agri-food irrigation		3.0	0.5	0.5
Recreational		3.5	1.5	1.5
Toilet and urinal flushing		5.0	3.0	3.5

[a] Log_{10} reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log_{10} reduction credits are available to meet the LRT through food processing (Appendix G).

Table B-4: Log_{10} reduction targets for stormwater (10^{-1} dilution or 10% contribution from sewage)[a]

Water End Use		Log_{10} Reduction Target for Viruses[b]	Log_{10} Reduction Target for Protozoa[b]	Log_{10} Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	5.0	4.0	4.5
	Outdoor	3.0	2.0	2.5
Agri-food irrigation[c]		6.0	5.5	6.0
Car/truck washing		4.5	3.5	4.5
Clothes washing		3.5	2.5	3.5
Cooling towers and evaporative condensers		3.5	3.0	3.5
Dust control/street cleaning		2.5	1.5	2.5
Non agri-food irrigation		2.5	1.5	2.5
Recreational		3.0	2.5	3.0
Toilet and urinal flushing		4.0	4.0	4.5

[a] Log_{10} reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log_{10} reduction credits are available to meet the LRT through food processing (Appendix G).

Table B-5: Log_{10} reduction targets for stormwater (10^{-3} dilution or 0.1% contribution from sewage)[a]

Water End Use		Log_{10} Reduction Target for Viruses[b]	Log_{10} Reduction Target for Protozoa[b]	Log_{10} Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	2.5	2.0	2.5
	Outdoor	0.5	0	0.5
Agri-food irrigation[c]		4.0	3.5	4.0
Car/truck washing		2.5	1.5	2.5
Clothes washing		1.5	0.5	1.5
Cooling towers and evaporative condensers		1.5	1.0	1.5
Dust control/street cleaning		0.5	0	0.5
Non agri-food irrigation		0.5	0	0.5
Recreational		1.0	0.5	1.0
Toilet and urinal flushing		2.5	2.0	2.5

[a] Log_{10} reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log_{10} reduction credits are available to meet the LRT through food processing (Appendix G).

Table B-6: Log_{10} reduction targets for rooftop collected rainwater and vehicle wash wastewater [a]

Water End Use		Log_{10} Reduction Target for Viruses[b]	Log_{10} Reduction Target for Protozoa[b]	Log_{10} Reduction Target for Bacteria[b]
Aesthetic water features	Indoor	Not applicable (NA)[d]	No data (ND)[e]	3.0
	Outdoor	NA	ND	1.0
Agri-food irrigation [c]		NA	ND	4.5
Car/truck washing		NA	ND	3.0
Clothes washing		NA	ND	2.0
Cooling towers and evaporative condensers		NA	ND	2.0
Dust control/street cleaning		NA	ND	1.0
Non agri-food irrigation		NA	ND	1.0
Recreational		NA	ND	2.0
Toilet and urinal flushing		NA	ND	3.0

[a] Log_{10} reduction targets were rounded to the nearest 0.5 units, given that there will be probable errors in estimating performance in field experiments (Refer to Schoen et al., 2017 and Li et al., *in prep*, for individual pathogen LRT estimates).

[b] The reference pathogens for viruses, protozoa, and bacteria are *Norovirus, Giardia lamblia,* and *Campylobacter jejuni*, respectively.

[c] Log_{10} reduction credits are available to meet the LRT through food processing (Appendix G).

[d] NA = Not applicable because human viruses are not common in rooftop sources (Sharvelle et al., 2017).

[e] ND = No direct data available for protozoa. Also, non-human sources of parasitic protozoa that could cause human infections is very low and limited to a few bird/animal sources(Li et al., *in prep*).

Appendix C: Management category descriptions and monitoring requirements

Table C-1: Management category descriptions and monitoring requirements

Management category	Description	Rationale	Validation, verification, and monitoring requirements
1	• Low user population AND water sources with the lowest concentration of pathogens (i.e., rooftop collected rainwater) for all uses. • Low user population AND water sources with increased concentrations of pathogens (i.e., municipal wastewater, greywater, stormwater) AND with low exposure potential end-use (as per Table 3).	• There are few people at risk of exposure and there is minimal opportunity for exposure to occur. Source water has little to no human contamination. • Risks are assumed to be adequately controlled in the WRSU system based on its design and operations. This means that no additional controls or procedures are needed. • Treatment mechanisms that are simple to operate and maintain with exposure controls will meet the LRTs.	Not required[1]
2	• Low user population AND water sources with increased concentrations of pathogens (i.e., municipal wastewater, greywater, stormwater) AND with med / high exposure potential end-use (as per Table 3). • High user population AND water sources with the lowest concentration of pathogens (i.e., rooftop	• There is an increase in number of persons exposed, but risk is limited by factors achieved through smaller user populations, water sources with lower concentration of pathogens, end-uses that have low human exposure potential. • Treatment mechanisms that are	**Technology Validation:** Recommended for new/unknown processes. Known processes may be used based on results of previous testing with similar source waters. **Verification Monitoring:** Recommended

	collected rainwater) for all uses. • High user population AND water sources with increased concentrations of pathogens (i.e., municipal wastewater, greywater, stormwater) AND with low exposure end use (as per Table 3).	simple to operate and maintain with exposure controls will meet LRTs OR a higher level of treatment complexity without exposure controls may be needed.	**Operational Monitoring:** Required
3	• High user population AND water sources with increased concentrations of pathogens (i.e., municipal wastewater, greywater, stormwater) AND with med / high exposure potential end-use (as per Table 3).	• There are large numbers of users at risk. • The source of water is likely to contain human waste and there is more opportunity for exposure. • More complex treatment mechanisms that require rigorous operations and maintenance are likely needed.	**Technology Validation:** Required for new/unknown processes. Known processes may be used based on results of previous testing with similar source waters. **Verification Monitoring:** Required during the commissioning process and repeated after **significant process/loading changes.** **Continuous Operational Monitoring:** Required

[1] The authority having jurisdiction may have more stringent requirements for WRSU systems within a single property that supersede these Health Guidelines.

Appendix D: Treatment options and $\log_{10}$ reduction credits

Various treatment process units and treatment trains can be used to achieve the $\log_{10}$ reduction target for a given combination of source water and end-use. Often treatment processes are more effective against one pathogen or another, consequently, the log reduction values should be considered for each pathogen class.

Pathogen reduction may occur through natural and biological process (Table D-1), filtration (Table D-2), and disinfection (Table D-3). For each process unit and microbial category (bacteria, viruses, and protozoa), $\log_{10}$ reduction credits (LRC) are assigned. The LRCs are based on either literature or experimental data from:

- Technology validation programs,
- Pilot studies conducted at universities or similar test-bed installations,
- Previous regulatory certifications,
- US EPA or NSF testing, or
- In situ testing.

The sum of the LRCs from the treatment plus the LRCs from the exposure controls (Appendix G) should meet or exceed the LRT for each microbial category.

Natural and biological processes

The inactivation and removal of pathogens in engineered water systems takes place through a number of natural mechanisms, including natural die-off, settling, predation, adsorption, and interception.

Table D-1: Log_{10} reduction credits[a] for natural and biological treatment processes (Sharvelle et al., 2017)

Process	Range of $\log_{10}$ reduction credits[a] for reference pathogens			Key factors that impact $\log_{10}$ reduction
	Virus	Protozoa	Bacteria	
Primary settling/septic tank	0.8	0.5	0.5	Retention time
Upflow anaerobic sludge blanket/anaerobic filter	0.8	0.5	0.5	Retention time
Packed bed filter	1	2	1	Hydraulic application rate, dosing frequency, filter bed surface area
Trickling filter	0.5	0.6	0.5	Hydraulic loading rate, filter surface area
Suspended growth reactor/ activated sludge	0.5	0.5	1	Biomass concentration, retention time
Lagoon	0.8	1	0.5	Retention time, pH
Treatment wetland	0.5	1.2	0.8	Retention time, packing material
Storage pond/reflection pool/water feature	1	1	1	Retention time, exposure to solar ultraviolet light

[a] Adapted from Petterson et al., 2016; NRMMC, EPHC, & NHMRC, 2008; Mara & Horan, 2003; Harrington et al., 2001.

Filtration processes

There are several filtration processes that can be used to remove particles, including pathogens, through size exclusion. Filtration serves as an important process, not only to remove pathogens, but also to improve the effectiveness of downstream inactivation by removing particulate matter that can interfere with subsequent inactivation processes, like ultraviolet (UV) light. The effectiveness of a chosen filtration process depends primarily on the porosity and permeability of the filter.

Advanced treatment, including coagulation and dual-media filtration, should comply with design criteria relating to aspects such as coagulant dosing, media depths and hydraulic flows. These would normally be accompanied by continuous operational monitoring for compliance with turbidity limits, to ensure that effective performance is maintained. The design specifications and operational limits should be set on a case-by-case basis and should be detailed in the WQMP as critical control points.

Table D-2: Log$_{10}$ reduction credits for filtration processes (Sharvelle et al., 2017)

Barrier	Log$_{10}$ reduction credits[a,b] for reference pathogens			Key factors that impact log$_{10}$ reduction
	Virus	Protozoa	Bacteria	
Slow sand filter	2	4	2	Sand effective size, filter bed depth
Dual media filter with coagulant	1	2	1	Coagulant dose, filter design
Cartridge/bag filter (5 to 10 microns)	0	0	0	Absolute pore size, hydraulic shock
Cartridge/bag filter (3 microns or less)	0	3	0	Absolute pore size, hydraulic shock
Cartridge/bag filter (1-micron absolute)	0	4	0	Absolute pore size, hydraulic shock
Diatomaceous earth (DE)	1	4	2	DE grade
Microfilter	1	6	6	Membrane age, pressure decay testing, integrity testing, integrity testing
Ultrafilter	6	6	6	Membrane age, pressure decay testing, integrity testing
Nanofilter	6	6	6	Membrane age, pressure decay testing
Reverse osmosis	6	6	6	Membrane age, seal integrity

[a] Adapted from Petterson et al., 2016; NRMMC, EPHC, & NHMRC, 2008; Mara & Horan, 2003; Harrington et al., 2001.

[b] Check manufacturer's specifications for log reduction claims.

Disinfection processes

Disinfection processes for pathogen inactivation include disinfection by chlorine, ozone, ultraviolet (UV) radiation, advanced oxidation, and pasteurization. The efficacy of alternative chemical disinfectants, such as bromine, iodine, and hydrogen peroxide as sole disinfectants are not well verified and if selected as a treatment, should be evaluated through bench testing, and documented.

Table D-3: Log$_{10}$ reduction credits for disinfection processes (Sharvelle et al., 2017)

Disinfectant	Unit	Dose for Corresponding Log$_{10}$ Reduction Credit			
		1 Log$_{10}$	2 Log$_{10}$	3 Log$_{10}$	4 Log$_{10}$
Enteric Viruses					
Free chlorine	mg•min/L		1.5 – 1.8	2.2 – 2.6	3 – 3.5
Chloramine[a]	mg•min/L		370 – 400	550 – 600	750 – 800
Peracetic acid	mg•min/L	NA	NA	NA	NA
Ozone	mg•min/L		0.25 – 0.3	0.35 – 0.45	0.5 – 0.6
Ultraviolet radiation[c]	mJ/cm^2	50 – 60	90 – 110	140 – 150	180 – 200
Advanced oxidation[d,e]	mJ/cm^2	10 – 20	50 – 60	70 – 80	110 – 130

Pasteurization (60°C)	second	140	280	420	560
Parasitic Protozoa					
Free chlorine	mg•min/L	2000 – 2600	NA	NA	NA
Chloramine[a]	mg•min/L	NA	NA	NA	NA
Peracetic acid	mg•min/L	NA	NA	NA	NA
Ozone	mg•min/L	4 – 4.5	8 – 8.5	12 – 13	NA
Ultraviolet radiation[c]	mJ/cm^2	2 – 3	5 – 6	11 – 12	20 – 25
Advanced oxidation[d]	mJ/cm^2	2 – 3	5 – 6	10 – 12	20 – 25
Pasteurization (60°C)	second	30	60	90	120
Enteric Bacteria					
Free chlorine	mg•min/L	0.4 – 0.6	0.8 – 1.2	1.2 – 1.8	1.6 – 2.4
Chloramine[a]	mg•min/L	50 – 70	95 – 150	140 – 220	200 – 300
Peracetic acid[b]	mg•min/L	10 – 25	40 – 60	75 – 125	150 – 200
Ozone	mg•min/L	0.005 – 0.01	0.01 – 0.02	0.02 – 0.03	0.03 – 0.04
Ultraviolet radiation[c]	mJ/cm^2	10 – 15	20 – 30	30 – 45	40 – 60
Advanced oxidation[d]	mJ/cm^2	4 – 6	6 – 8	8 – 10	10 – 12
Pasteurization (60°C)	second	50	100	150	200

[a] Due to interferences with chloro-organic compounds, when chloramine is used as a disinfectant, $\log_{10}$ reductions can only be recognized if the actual dosage of monochloramine is known, not just the amount of combined chlorine.

[b] Linden et al., 2012.

[c] US EPA, 2006.

[d] Based on ultraviolet (UV) and hydrogen peroxide (H_2O_2) with 10 milligrams per liter (mg/L) H_2O_2 (Sun et al., 2016; Bounty et al., 2012).

[e] Based on the inactivation of Adenovirus (Bounty et al., 2012).

mg•min/L = Milligram-minutes per litre

mJ/cm2 = Millijoules per square centimetre.

NA = Not applicable

The efficacy of a disinfection process is impacted by a number of factors.

- Chemical disinfection (free chlorine, chloramine, peracetic acid, ozone) is affected by turbidity, organic carbon content, ionic strength, pH, temperature, and non-target reactants in water.
- Particles in water can inhibit effective disinfection through shading (in the case of UV) and shielding embedded pathogens. Larger particles may require more time for a disinfecting agent to penetrate the particle and reach an embedded pathogen; therefore, for any disinfectant to be effective, particles larger than 10 microns (which can shade or shield pathogens) must be removed (Asano et al., 2007).
- For chemical disinfectants, the disinfectant residual (milligrams per litre) and the contact time (minutes) (when the two factors are multiplied it is known as the CT-value), have the most influence on what LRC is achievable.
- For UV-based disinfection, the power of the UV light that is used (millijoules per square centimeter) determines the LRC, and for pasteurization, it is temperature (°C) and time (seconds) that determines the LRC.

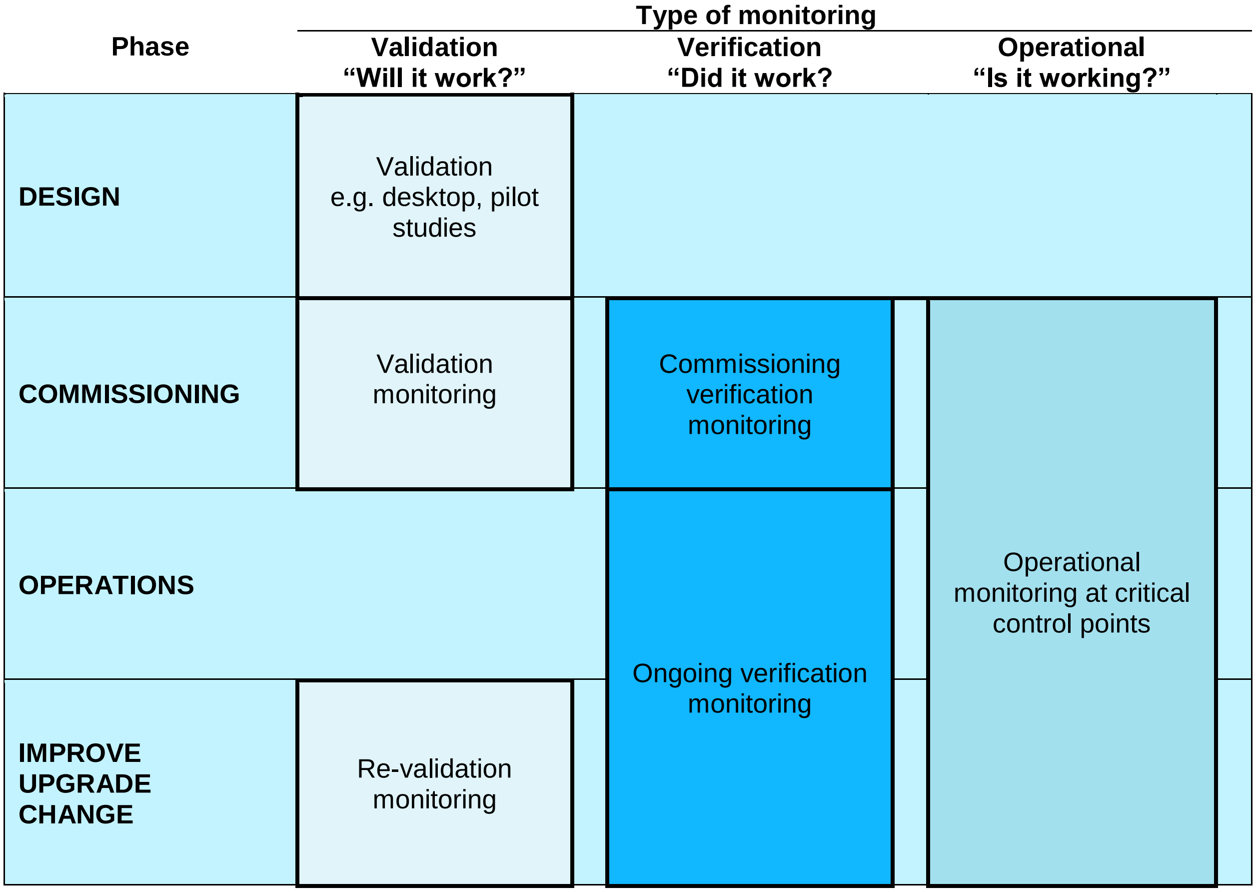
For more information, the US EPA guidance can be used to identify appropriate disinfection regimes (US EPA 1999, 2003).

Appendix E: Enhancing reliability of process design and control features by management category

Table E-1: Examples of process design and control features to enhance the reliability of a water system and the applicable management category (Sharvelle et al., 2017)

Feature	Description	Management Category		
		1	2	3
Alarm systems	Automated notification at critical control points to indicate when WRSU system is operating outside the design parameters and potentially causing a hazard to health and safety, or damage to the system. Alarm conditions should not be capable of being bypassed or overridden except for diagnostic or manual operation of system.		☐	☐
Backup dispersal or discharge system	Alternative location for the management of inadequately treated or excess water.	☐	☐	☐
Equalization of flows	The balancing of source water quality, flow rate, and demand for product water can improve process stability and maximize non-potable water use.		☐	☐
Fail-safe mechanisms	Features that result in a controlled and non-hazardous automatic shutdown of the process in the event of a malfunction.		☐	☐
Make-up water systems	Automatic addition of water from back-up supply in the event that water is not sufficient for the end-use.			☐
Multiple barrier concept	The use of treatment barriers in series, such that the malfunction of one process does not compromise the performance of the entire treatment train.	☐	☐	☐
Operational barriers	May include operation and monitoring plans, failure and response plans, and operator training and/or certification.	☐	☐	☐
Operational control points	Monitoring system for process units that support critical control points. Operational control points are not used specifically for pathogen control.		☐	☐
Rapid response time	The availability of on-call RME service personnel to address alarms within a short time frame will reduce downtime and prevent larger issues from developing.		☐	☐
Supervisory Control And Data Acquisition (SCADA) and telemetry systems	The use of systems for remote monitoring such that real-time data and alarm status can be reviewed remotely.		☐	☐
Sensors and instrumentation for process monitoring	Sensors for continuous monitoring and assurance that pathogen log$_{10}$ reduction targets are met.	☐	☐	☐
Source control measures	Overall reliability can be enhanced by eliminating constituents (e.g., biocides) that could have a negative impact on the treatment system.	☐	☐	☐

Appendix F: Validation, verification, and operational monitoring



Phase	Type of monitoring		
	Validation “Will it work?”	Verification “Did it work?	Operational “Is it working?”
DESIGN	Validation e.g. desktop, pilot studies		
COMMISSIONING	Validation monitoring	Commissioning verification monitoring	Operational monitoring at critical control points
OPERATIONS		Ongoing verification monitoring	
IMPROVE UPGRADE CHANGE	Re-validation monitoring		

Figure F-1: Validation, verification, and operational monitoring comparison (NSW Government, 2015)

Appendix G: Log_{10} reduction credits for exposure controls and management practices

Exposure controls and management practices can be used to fully or partially meet the required $\log_{10}$ reduction targets. Table G-1 outlines some of the commonly used and accepted methods.

Table G-1: Log_{10} reduction credits for select exposure controls and management practices (NRMMC, EPHC, AHMC, 2006).

Control measure	Reduction in exposure to pathogens [a]
Food Processing	
Cooking or processing of produce (e.g., cereal, wine grapes)	5 log
Controlling methods of application and application rates [b]	
Drip irrigation of crops	2 log
Drip irrigation of crops with limited to no ground contact (e.g., tomatoes, capsicums)	3 log
Drip irrigation of raised crops with no ground contact (e.g., apples, apricots, grapes)	5 log
Subsurface irrigation of above ground crops	4 log
Spray drift control (micro-sprinklers, anemometer systems, inward-throwing sprinklers, etc.)	1 log
Drip irrigation of plants/shrubs	4 log
Subsurface irrigation of plants/shrubs or grassed areas	5 log
Setting withholding periods	
Withholding periods: agri-food irrigation [c]	0.5 log/day
Withholding periods: non-agri food irrigation [d]	0.4 log/4 hours viruses 0.7 log/4 hours bacteria
Controlling public access and application times [e]	
No public access during irrigation	2 log
No public access during irrigation and limited contact after (non-grassed areas) (e.g., food crop irrigation)	3 log
Buffer zones (25–30m)	1 log
Drive-through vehicle wash	3 log

[a] Includes reduction in viruses, bacterial and protozoa, except where otherwise specified.

[b] Mara & Horan (2003).

[c] Based on virus and bacteria inactivation. Protozoa will be inactivated if withholding periods involve desiccation (Asano et al., 1992; Petterson et al., 2001; Tanaka et al., 1998).

[d] Page, Sidhu, & Toze (2015).

[e] Fencing combined with warning signs can be used to restrict or control access. Fencing can range from simple railings to security mesh, depending on the quality of recycled water and site characteristics.

Appendix H: Operational monitoring and verification parameters and surrogates for treatment process units

Table H-1: Parameters used for continuous monitoring (Sharvelle et al., 2017; Tchobanoglous et al., 2015)

Treatment process unit	Monitoring parameters and surrogates	
Natural and biological processes		
Primary settling/septic tank	- Flow rate through the system	- Solids depth
Upflow anaerobic sludge blanket/anaerobic filter	- Flow rate through system - Biological oxygen demand (BOD)	- Sludge blanket depth
Suspended growth reactor/ activated sludge Treatment wetland Storage pond	- Retention time in treatment unit - pH, temperature, conductivity, and other parameters in reactor - Cyanobacteria levels and toxin concentrations	- Flow rate - Biomass concentrations and wastage rates from reactor - Process-specific parameters - Visual indicators
Membrane bioreactor	- Membrane integrity - Membrane flux - Transmembrane pressure - Permeate water quality - Dissolved oxygen	- Temperature - Process pH - Solids retention time - Food-to-microorganism ratio - Flow rate
Filtration processes		
Slow sand filter Cartridge/bag filter	- Turbidity - Particle size distribution - Flow rate through filter/total volume filtered - Pressure differential/vacuum pressure	- Filter maintenance/cleaning/backwashing cycles - Membrane age/end-of-life indicators - Pressure decay testing
Dual media filter with coagulant Diatomaceous earth (DE) Packed bed filter Trickling filter	- Filtration rate - Filter run time - Backwash rate - Headloss across system	- Temperature, pH, alkalinity, and particle size analysis/distribution - Turbidity. - Coagulant type, dose, and blending system

Treatment process unit	Monitoring parameters and surrogates	
Microfilter Ultrafilter Nanofilter Reverse osmosis	- Electrical conductivity - Membrane integrity - Membrane flux - Transmembrane pressure - Permeate water quality - Process turbidity - pH	- Total organic carbon and particle analysis - Solids retention time / hydraulic retention time - Dissolved oxygen - Temperature - Flow rate - Headloss across system - Pressure decay test or bubble point test
Activated carbon/ion exchange contactors	- Effluent constituents - Flow rate through contactor - Total bed volumes processed	- Pressure differential across contactor - Bed regeneration/cleaning/backwashing cycles.
Disinfection processes		
Free chlorine and chloramine	- Chlorine residual (free or chloramine) - pH - Turbidity/particle size distribution in flow entering the contact tank	- Flow rate through contact tanks/contact time - Amount of chlorine remaining in chlorine feed tank - Temperature - Oxidation reduction potential (ORP)
Peracetic acid	- Concentration	- Contact time
Ozone	- Ozone residual - UV absorbance (UVA) at 254 nanometers and UV transmissivity (UVT) - ORP - Turbidity/particle size distribution in flow entering the contact tank	- Flow rate through venturi injector. - Oxygen generator output oxygen concentration and flow rate - Inlet and outlet pressure at venturi, vacuum at venture - Power consumption by oxygen concentrator and ozone generator
Ultraviolet (UV) radiation	- UV intensity/applied dose - Turbidity/particle size distribution in flow entering UV contactor - Color (absorbance at wavelengths ranging from 420 – 460 nm). - UVA_{254} and UVT	- ORP - Flow rate through UV contactor - Lamp age and/or lamp output - Ballast functionality - Cleaning frequency
Advanced oxidation (UV and hydrogen peroxide (H_2O_2))	- Electrical conductivity - Total organic carbon (TOC) - ORP - Color	- UVA_{254} and UVT - Turbidity/particle size distribution in flow entering reactor - Process flow rate
Other		
Sensors	- Power consumption - Calibration schedule - Maintenance schedule	

Treatment process unit	Monitoring parameters and surrogates	
Distribution system	- Residual disinfectant (when used) - Temperature (where opportunistic pathogen growth a concern)	- Pressure in pressure tank/distribution system - Flow rates and levels in non-potable water system process tanks, including product water, make-up water, source water, and discharged flow
Over-irrigation control	- Soil moisture content - Irrigation time	
Accidental exposure control	- Timing of irrigation - Direction of sprinkler throw before application - Wind direction before application	- Presence, currency, and comprehension of user agreements - Presence, integrity and clarity of fittings - Signage and other end-user controls

** High ORP values are representative of strong oxidative environments where pathogens can be destroyed due to chemical oxidation.

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