Final **Report**

Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems




Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems

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Water Research Foundation

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- Effectively communicate the results and progress of our research and innovation activities in a timely manner.

Interwoven in WE&RF's mission and goals is the need to provide industry leadership, to collaborate with interested parties and our partners, to uphold the integrity of the scientific process to ensure research is unbiased and is credible, and to do so in a transparent and accountable fashion that provides value to our subscribers and partners.

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National Water Research Institute Staff

The National Water Research Institute (NWRI) formed and administered the Independent Advisory Panel to provide expert peer review of the technical, scientific, and regulatory aspects with the reuse of alternate water sources to develop the draft and final technical public health standards. NWRI staff members who assisted with the Panel effort included:

- Brandi Caskey, *Administrative Manager*
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Project Sponsors

- San Francisco Public Utilities Commission
- Water Research Foundation
- Water Environment & Reuse Foundation

Public Health Coalition

The San Francisco Public Utilities Commission (SFPUC) organized volunteers stakeholders to participate on a Public Health Coalition for onsite treatment systems to: 1) evaluate existing standards for alternate water sources; 2) identify data gaps and research needs; and 3) develop recommended guidelines to help local public health agencies implement these projects and establish, to the extent feasible, a uniform practice among states. The Public Health Coalition participated in two workshops and provided input and review on the draft report to the Independent Advisory Panel. Members of the coalition include representatives from the following public agencies:

- Los Angeles County Department of Public Health
- New York City Department of Environmental Protection
- San Francisco Department of Public Health
- Hawaii State Department of Public Health
- Oregon Department of Environmental Quality
- Minnesota Department of Health
- Washington State Department of Health

Stakeholder Advisory Committee

Representatives of the following stakeholder organizations were invited to provide input to the Independent Advisory Panel and feedback on draft documents:

- Arizona Department of Environmental Quality
- Austin Water Utility
- California State Water Resources Control Board, Division of Drinking Water
- City of Santa Monica, Office of Sustainability and the Environment
- Colorado Department of Public Health and Environment
- Los Angeles County Department of Public Health
- Denver Water
- DC Water (District of Columbia Water and Sewer Authority)
- District of Columbia Department of Energy and Environment
- Hawaii State Department of Public Health
- Los Angeles Department of Water and Power
- Minnesota Department of Health
- New York City Department of Environmental Protection
- Portland Water Bureau
- Province of Alberta Municipal Affairs, Safety Services
- San Francisco Department of Public Health
- San Francisco Public Utilities Commission
- Santa Monica Public Works
- Seattle Public Utilities
- United States Environmental Protection Agency, Office of Research and Development
- Washington State Department of Health

Preface

In 2015, the National Water Research Institute (NWRI) of Fountain Valley, California, a 501c3 nonprofit organization, appointed water industry experts to an Independent Advisory Panel (Panel) to provide expert peer review of the technical, scientific, and regulatory aspects of onsite water treatment systems. The goal of this project was to provide 1) recommendations and guidance regarding treatment requirements protective of public health and 2) a management framework for the appropriate use of onsite-treated alternate water sources for non-potable applications, including water quality parameters and monitoring criteria.

NWRI formed the Panel on behalf of the San Francisco Public Utilities Commission (SFPUC), Water Environment Research Foundation (WERF), WateReuse Research Foundation (WRRF),[1] and Water Research Foundation (WaterRF). SFPUC's involvement with the project began in 2012, when it collaborated with the City of San Francisco's Departments of Building Inspection and Public Health to develop a local program for regulating onsite water usage. The program created a process for reviewing, approving, and permitting the installation and operation of private onsite water treatment systems.

In May 2014, SFPUC expanded the project by collaborating with WERF and WaterRF to convene a meeting on "Innovation in Urban Water Systems,"[2] which brought together representatives of local, state, and federal agencies from across North America to discuss onsite water treatment systems, including barriers to implementation, opportunities to expand usage, and research needs. Meeting attendees confirmed that communities face similar critical issues when developing, implementing, and scaling onsite water treatment systems. All agreed on the need for appropriate and consistent water quality standards and monitoring strategies to protect public health. Attendees also discussed the challenges associated with a lack of national or regional standards, such as determining if water quality standards should reside in plumbing codes or elsewhere, and deciding who should be an authority in developing such standards. Agencies expressed concern about ensuring the protection of public health while maintaining scale-appropriate commitments in terms of risk, burden, and cost. Similarly, agencies recognized that a process for permitting onsite water treatment systems must be streamlined and straightforward to implement, encouraging interested parties to implement onsite use.

Meeting participants identified two primary institutional barriers to onsite water treatment:

- Developing a local program to manage onsite water treatment systems.
- Developing scale-appropriate water quality criteria and monitoring.

To address the first barrier, attendees developed the *Blueprint for Onsite Water Systems: A Step-by-Step Guide for Developing a Local Program to Manage Onsite Water Systems*. The Blueprint was released in September 2014 and serves as a guide for communities interested in implementing a program to oversee onsite water treatment systems.

This project, called the *Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems* (WERF Project No. SIWM10C15), addressed the second

[1] WERF and WRRF merged in 2016 to form the Water Environment & Reuse Foundation (WE&RF).
[2] More information is available at www.sfwater.org/np/iuws (last accessed 10/27/2016).

barrier of developing a framework to establish scale-appropriate water quality criteria and monitoring. The goal of the project was to prepare recommendations on the following:

- Water quality pathogen targets for multiple types of alternate water sources, including graywater, blackwater, roof runoff, and stormwater.
- Monitoring regimes for water quality.
- Management considerations for systems.
- Strategies for permitting projects.
- Applications and end uses of treated alternate water sources.

This effort included the participation of both an NWRI Panel and a Stakeholder Advisory Committee, which met together to discuss content for the guidance document at two interactive workshops held in October 2015 and April 2016. The Panel members include technical experts in the fields of risk assessment, microbiology, and water quality standards and regulations. Stakeholders representing public health organizations and water utilities from cities in 10 states and a Canadian province participated at the two workshops. The purpose of these workshops was to facilitate discussion on current regulatory and water quality parameters and solicit feedback from stakeholders regarding the content of the Panel's report. Stakeholders also reviewed the draft final report and provided feedback to the NWRI Panel.

The result is this panel report, which provides a risk-based framework to develop public health guidance for decentralized non-potable water systems.

Abstract and Benefits

Abstract:

Decentralized Non-Potable Water (DNW) Systems are used to collect, treat, and re-use water from local sources (e.g., roof runoff, stormwater, graywater, and wastewater) for various non-potable applications in individual buildings, neighborhoods, or districts. Guidance can help support the widespread adoption of DNW systems, particularly regarding management practices, treatment targets, and monitoring. The goal is to ensure the protection of public health.

Included in this report is a risk-based framework to develop public health guidance for DNW systems, focused on the following:

- Performance-based $\log_{10}$ reduction targets (LRTs) for the treatment of pathogens.
- Design to achieve the LRTs.
- Consistent management and monitoring practices.
- Consistent permitting and reporting practices.

Benefits:

- Provides guidance to help regulators develop programs that enable the pragmatic design and operation of DNW systems.
- Provides guidance to help select LRTs for pathogens based on the source of water and expected end use of the resulting non-potable water supply.
- Provides a flexible framework that can be 1) adapted to new water sources and end uses and 2) modified based on experience gained in operating DNW systems and advances made in approaches and methodologies to estimate risk-based LRTs.

Keywords: Decentralized Non-Potable Water System, onsite water treatment, roof runoff, stormwater, graywater, wastewater, blackwater, public health protection, and $\log_{10}$ reduction of pathogens.

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Acronyms and Abbreviations

amu	Atomic Mass Units
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
C	Residual Disinfectant Concentration
CASQA	California Stormwater Quality Association
CPDF	Cumulative Probability Density Function
DALY	Disability Adjusted Life Year
DE	Diatomaceous earth
DNW System	Decentralized Non-Potable Water System
FIO	Fecal Indicator Organisms
HACCP	Hazards analysis critical control point
HOA	Homeowner Association
HOCl	Hypochlorous Acid
HPC	Heterotrophic Plate Count
HSE	Health and Safety Executive
HVAC	Heating, Ventilation, and Air Conditioning
IPC	International Plumbing Code
LRT	Log_{10} Reduction Target
LRV	Log_{10} Reduction Value
NSF	National Sanitation Foundation
NTU	Nephelometric Turbidity Units
NWRI	National Water Research Institute
O&M	Operation and Maintenance
OCl^-	Hypochlorite Ion
ORP	Oxidation-Reduction Potential
P3	Public Private Partnership
PAR	Permit Application Report
Pe/d	People exposed per day
PCP	Pathogen Control Point
ppy	Per person per year
QA/QC	Quality assurance/quality control
QMRA	Quantitative Microbial Risk Assessment

QSD	Qualified Stormwater Pollution Prevention Plan Developer
QSP	Qualified Stormwater Pollution Prevention Plan Practitioner
qPCR	Quantitative (or real-time) polymerase chain reaction
RME	Responsible Management Entity
SCADA	Supervisory Control And Data Acquisition
SFPUC	San Francisco Public Utilities Commission
SWPPP	Qualified Stormwater Pollution Prevention Plan
T	Contact time
UPC	Uniform Plumbing Code
UV	Ultraviolet light
UVA	Ultraviolet light absorbance
UVT	Ultraviolet light transmittance
VLRV	Validated Log_{10} Reduction Value
WaterRF	Water Research Foundation
WE&RF	Water Environment & Reuse Foundation
WERF	Water Environment Research Foundation
WHO	World Health Organization
WRRF	Water Reuse Research Foundation

Terminology

General Terms	
Commissioning	The activities associated with bringing a new process, such as a water system, into normal working condition (i.e., new or re-commissioning after a non-operational period).
Critical Control Point	Locations in a treatment process train, including specific processes and chemical addition steps, that have a direct impact on the quality of finished water (in this report, for pathogen management) and may affect the safety of delivered water.
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.
Decentralized Non-Potable Water (DNW) System	A system in which water from local sources is collected, treated, and used for non-potable uses at the building- to district/neighborhood-scale, generally at a location near the point of generation.
Disability Adjusted Life Year	The composite measure of years lost to disability (YLD) with non-fatal conditions, injuries, and diseases, plus the age-specific mortality [years of potential life lost (YPLL) to fatal conditions]. Water guidelines from Australia, Canada, and the World Health Organization specify a water exposure annual benchmark of one DALY per million people, which is similar to an annual infection risk of 10^{-3} per person for Rotavirus or *Cryptosporidium* spp. and 10^{-4} per person for *Campylobacter* spp.
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).
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 (e.g., high community prevalence and environmental persistence) that make it a useful index of other pathogens in the same microbial group (i.e., virus, bacteria, or parasitic protozoan). In this report, a range of enteric viruses (i.e., Norovirus, Adenovirus, Rotavirus), enteric bacteria (i.e., *Campylobacter jejuni, Salmonella enterica*) and parasitic protozoa (i.e., species of *Cryptosporidium* and *Giardia*) was selected as reference pathogens to derive $\log_{10}$ reduction targets for the control of enteric pathogens in non-potable water applications.

Terms for Water Sources	
Blackwater	Wastewater originating from toilets and/or kitchen sources (i.e., kitchen sinks and dishwashers).
Blended Water	Various combinations of water derived originally from blackwater, graywater, wastewater, roof runoff, stormwater, condensate, or foundation water. Notably, ordinances in many areas do not allow the combination of roof runoff and/or stormwater with wastewater as part of the wastewater collection system due to documented concerns associated with sanitary sewer overflows and/or the treatment and hydraulic capacity of publicly owned treatment works. Blended water is the purposeful aggregation of water for use as non-potable water supply.
Condensate	Water vapor that is converted to a liquid and collected (the most common source in buildings being equipment for air conditioning, refrigeration, and steam heating).
Foundation Water	Shallow groundwater collected from the drainage around building foundations or sumps.
Graywater	Wastewater collected from non-blackwater sources, such as bathroom sinks, showers, bathtubs, clothes washers, and laundry sinks.
Roof Runoff	Precipitation from a rain or snowmelt event that is collected directly from a roof surface not subject to frequent public access.
Shallow Groundwater	Groundwater located near the ground surface in an unconfined aquifer and subject to contamination from the infiltration of surface sources.
Stormwater	Precipitation runoff from rain or snowmelt events that flows over land and/or impervious surfaces (e.g., streets, parking lots, and rooftops). In this report, stormwater also is defined as runoff from roofs with frequent public access.
Wastewater	Water collected from combined graywater and blackwater sources (also referred to as sewage). Also: • *Domestic wastewater* refers to wastewater only collected from residential uses. • *Municipal wastewater* refers to wastewater collected on a municipal scale that may include industrial wastewater.

Terms for Scale	
District	A defined service area for a Decentralized Non-Potable Water System that covers multiple properties and may cross public rights-of-way.
Multi-User Building	Any building that is not a single residence (e.g., multi-residential apartment, commercial, mixed use, and others).
Municipal	A water or wastewater system for large urban service areas consisting of residential, commercial, and/or industrial activities.
Single-Owner Occupied	A stand-alone building within its own lot occupied by one group of residents.

Terms for Treatment	
Contact Time (T)	The time for a reaction to take place in a unit process reactor (usually taken as the retention time for 90% of the flow volume, as determined using a tracer study).
CT	The product of residual disinfectant concentration and time (mg•min/L).
Fit-for-Purpose Water	Water treated to a quality matching the quality requirements for the intended use for that water. Appropriate water quality for the intended use is determined based on the agreed level of risk to human health and environmental quality for that use.
Log_{10} Reduction	The removal of a pathogen or surrogate in a unit process expressed in log_{10} units. A 1-log_{10} reduction equates to 90% removal, 2-log_{10} reduction to 99% removal, 3-log_{10} reduction to 99.9% removal, and so on.
Log_{10} Reduction Target (LRT)	The log_{10} reduction target for the specified pathogen group (i.e., viruses, bacteria, or protozoa) to achieve the agreed level of risk to individuals (e.g., 10^{-4} infection per year).
Log_{10} Reduction Value (LRV)	The observed log_{10} pathogen reduction performance for a unit process operated under controlled and defined conditions. The LRV is equal to the difference in concentration of an added or indigenous pathogen or surrogate (reported in log_{10} units) between paired samples of influent and effluent.
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.
National Sanitation Foundation (NSF) 350	A certification process for treatment technologies used to recycle graywater to flush toilets.
Residual Disinfectant Concentration (C)	The concentration of a disinfectant agent in a reactor after a specified retention time.
Validated Log_{10} Reduction Value (VLRV)	The log_{10} reduction value for a unit process determined through validation testing over the range of anticipated operational conditions and taken to be representative of the lower bound of performance (typically, at the lower 5- or 10% value).

Terms for Disinfection	
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.
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.
Fecal Indicator	A biological, chemical, or physical marker of human and non-human fecal matter.

Terms for Disinfection	
Fecal Indicator Organism	A microorganism whose presence in water indicates the probable presence of fecal pollution and, therefore, possible presence of pathogens in the water.
Free Chlorine	The concentration of chlorine in water that is present as hypochlorous acid (HOCl) and/or hypochlorite ion (OCl^-).
Ozone Disinfection	Ozone gas, a strong oxidant, is applied to water to inactivate bacteria, protozoa, and viruses.
Peracetic Acid	A strong oxidant formulated from hydrogen peroxide and acetic acid that is effective for the inactivation of bacteria, protozoa, and viruses.
Surrogate	A biological, chemical, or physical marker of the efficacy of a process step.
Surrogate Organism	An organism that behaves the same as the pathogen of interest in a treatment process. In the context of Decentralized Non-Potable water systems, surrogate organisms are used to verify the $\log_{10}$ reduction of pathogens in a treatment process train.
Total Chlorine	The sum of free chlorine and combined chlorine.
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.

Terms for Monitoring	
Challenge Test	The evaluation of a unit treatment process 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.
Continuous Verification Monitoring	Ongoing confirmation of system performance using sensors for continuous observation of selected parameters, including surrogate parameters that are correlated with pathogen $\log_{10}$ reduction target requirements.
Field Verification	Performance confirmation study conducted using challenge testing, including surrogate microorganisms and/or other non-biological surrogates, usually during startup and commissioning and may be repeated as needed. The need for, duration, and extent of the field verification procedure will depend on characteristics of the Decentralized Non-Potable Water System.
Pathogen Control Point	A treatment barrier designed specifically to reduce pathogens.
Responsible Management Entity (RME)	A person, corporation, or governmental body with ultimate legal responsibility for the performance of a Decentralized Non-potable Water system.
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*.

Executive Summary

ES.1 Introduction

The use of local water sources (e.g., roof runoff, stormwater, graywater, and wastewater) to meet demands for non-potable water, building-by-building, is gaining interest as an approach to minimize the import and export of water (NRC, 2016), ensure reliable water sources, increase water supply resiliency, and promote energy efficiency. In response, an Independent Advisory Panel (the Panel) was organized in 2015 to address the need for guidance for onsite water treatment and usage. The final product of the Panel process is this report, which focuses on Decentralized Non-Potable Water (DNW) Systems, defined as systems in which water from local sources is collected, treated, and used for non-potable applications at the building, neighborhood, and/or district scale, generally at a location near the point of generation.

Currently, national standards or guidelines for DNW systems are not available in the United States. In particular, guidance is needed on setting appropriate performance criteria and developing an appropriate structure to manage, monitor, and permit DNW systems. The purpose of this report is to provide information and guidance through a risk-based framework to help state and local health departments develop DNW systems that are adequately protective of public health. This report is intended for use by technical staff at public health agencies.

A key consideration during the development of the framework was the need to provide a flexible approach that enables the pragmatic design and operation of DNW systems, ensuring the reliable delivery of water that is protective of public health and meets the needs of different communities across the United States. By design, the framework addresses multiple water sources and end uses, and can be expanded to include those not covered in this report. For example, the Panel developed this framework specifically to address applications in multi-user buildings (i.e., multi-residential, commercial, and mixed-use buildings) and at the district-scale; however, it is applicable across different scales. Source waters addressed in this report include blackwater, graywater, domestic wastewater, roof runoff, stormwater, and foundation water. Although the Panel only considered non-potable end uses for this report (i.e., toilet flushing, clothes washing, unrestricted access irrigation and dust suppression, and cooling towers), the framework can be used to establish guidance for any combination of source waters and end uses.

The overall framework for implementing a DNW system is outlined in Figure ES-1 and described further in Chapter 1. It includes risk-based guidance on estimated $\log_{10}$ reduction targets (LRTs) for pathogens to inform the design of DNW systems based on multiple combinations of source water end use, as discussed in Chapters 3 and 4. Technology validation may be needed to ensure unit treatment processes achieve these LRTs when validation data are not available for log reduction values achieved for the process specific to the source water to be used (Chapter 6). The design and plan for management (Chapter 5), commissioning, monitoring, and reporting are incorporated into a Permit Application Report. Continuous monitoring should target select parameters correlated with system performance (Chapter 6), and routine reporting is recommended (Chapter 8). The Panel designed this framework to be flexible in anticipation that some guidance will change over time.

1. Design

- Select the appropriate $\log_{10}$ reduction target (LRT) for the end use.
- Select the appropriate treatment process train to achieve the LRT.
- Receive approval by a Professional Engineer.

2. Management Plan

- Specify the Responsible Management Entity (RME) Management Category (1 to 3).
- Designate the roles and responsibilities of the RME.

3. Permit Application Report Submission

- Specify the design, RME, assurance of reliability via monitoring, commissioning plan, operations and maintenance (O&M) plan, and plan for managing the distribution system.
- Receive sign-off by a Registered Professional Engineer and approval by the regulatory agency.

4. Construction and Commissioning

- Demonstrate via field verification, when required.
- Submit the Commisioning Report (which includes field verification results and the final monitoring plan).

5. Operational Monitoring

- Continuously monitor, at high frequency, surrogate water quality and/or operational parameters correlated to the LRTs.
- Include controls for the production of water that is out-of-compliance.

6. Reporting

- Include violations and incidents.
- Use a format for routine reporting that is simple to review.
- Receive approval and enforcement by the regulatory agency.

Figure ES-1: Proposed framework for implementing Decentralized Non-Potable water systems.

ES.2 Risk-Based Management Considerations for Decentralized Non-Potable Water Systems

When considering the requirements for the design, management, operation, monitoring, and reporting of a DNW system, it is important to establish management requirements that are adequate and appropriate, given the risk level potential for the particular system. As the complexity and/or size and customer base of a DNW system increases, the level of regulatory oversight and related management requirements will increase accordingly. Hence, the Panel loosely defined three Management Categories in this framework, as shown in Table ES-1, to guide the level of oversight for a DNW system. Ultimately, the regulating authority will decide how individual DNW systems fit within these three Management Categories.

ES.3 Risk-Based Pathogen Reduction Targets

The pathogen reduction targets discussed in this report were derived from a Quantitative Microbial Risk Assessment (QMRA), which is a scientific approach used to estimate the potential risks to human health resulting from exposures to microbial hazards (i.e., human pathogenic viruses, bacteria, and protozoa)

(WHO, 2016). LRTs were developed for each source water and end use addressed in this report based on attaining an annual "tolerable" infection risk of either 10^{-4} or 10^{-2} per person (refer to Table 3-3 in Chapter 3) based on studies in the peer-reviewed literature. LRTs are recommended for each class of enteric pathogen (i.e., enteric viruses; enteric bacteria; and parasitic protozoa). A properly designed system – together with appropriate construction, operation, and maintenance – will help ensure LRTs are achieved for each group of pathogens. Controlling water-based opportunistic pathogens (e.g., *Legionella pneumophila, Pseudomonas aeruginosa,* and non-tuberculous mycobacteria) that may grow post-treatment within engineered systems is discussed in Chapter 7.

Table ES-1: Risk-Based Management Categories for Decentralized Non-Potable Water Systems

Management Category	Description of Category
1	• Lowest user population. • Non-potable water sources with the lowest concentrations of pathogens. • Non-potable water uses with the lowest human exposure. • Treatment mechanisms that are simple to operate and maintain.
2	• Some increase in the number of persons exposed, but strong mitigating factors achieved through combinations of small user populations. • Non-potable water sources with the lowest concentrations of pathogens. • Non-potable water uses with low human exposure. • Treatment mechanisms that are simple to operate and maintain.
3	• More exposure risk due to the combinations of increased user populations. • Non-potable water sources with higher concentrations of pathogens. • Non-potable water uses with increased likelihoods of exposure. • More complex treatment mechanisms that require rigorous operation and maintenance.

ES.4 Selecting Unit Operations to Achieve Pathogen Reduction Targets

After selecting an appropriate LRT for the source water and end use, a designer should select the unit processes that achieve those LRTs (see Figure ES-1). Data are available on LRTs achieved through biological treatment, filtration, and other disinfection processes. A designer should use this data to sum the predicted $\log_{10}$ reductions for each pathogen group (i.e., enteric viruses, enteric bacteria, and parasitic protozoa) for each unit process to ensure that LRTs can be achieved. It may be necessary to verify that the treatment system, as designed, will meet these LRTs, as described in Chapter 6.

ES.5 Tiered Management Approach for Decentralized Non-Potable Water Systems

A responsible management entity (RME) must be identified (see Figure ES-1) to oversee the following:

- Developing, financing, designing, constructing, and operating the system.
- Interfacing with both the 1) regulating agency and 2) end user of the treated water.

Identifying the most appropriate RME model for a specific community will depend on a number of factors, including: 1) existing local water regulatory structure; 2) water rights; 3) physical characteristics of a community's water assets; 4) ownership of water assets; 5) authorized powers; 6) available resources of the owners of water assets; and 7) perspectives of local stakeholders on risk management. DNW system management should correspond with its Management Category, as described in Chapter 2. As the complexity and/or size and customer base of the DNW system increases, the level of regulatory oversight and related management requirements will increase accordingly.

There are several options for RME structure and ownership, including: 1) municipality; 2) quasi-governmental authority; 3) public nonprofit; 4) private non-profit (association); 5) private for-profit; and 6) public-private partnership. Selecting an appropriate ownership model will vary by project, set-up of the RME, and existing regulatory framework.

ES.6 Monitoring for Commissioning and Normal Operations

Monitoring and control systems assess the operation, performance, and status of a given component or process of a treatment system. Because pathogens and fecal indicator organisms (FIOs) cannot be measured continuously, process monitoring should involve the use of surrogate parameters that correlate with the integrity of the treatment process. Preferably, surrogate parameters should be monitored continuously using appropriate sensors and instrumentation; therefore, the purpose of performance target monitoring is to ensure that the treatment barriers – designed to meet the requirements of microbial risk assessment (i.e., LRTs) – are operating as intended. It is analogous to the best management practices used in operating drinking water systems.

Although many possible monitoring configurations are available for DNW systems, the three primary forms of monitoring include validation testing, field verification, and continuous verification monitoring.

PRIMARY FORMS OF MONITORING FOR DNW SYSTEMS

- **Validation testing.** A treatment technology process evaluation study conducted using challenge testing with target or surrogate pathogens over a defined range of operating conditions, usually conducted at a test facility or *in situ.*
- **Field verification**. Performance confirmation study, using biological and/or chemical surrogates, typically conducted during commissioning (if required) and repeated later (if needed). In some cases, indigenous organisms are used for process verification. The need for, duration, and extent of the field verification procedure will depend on the characteristics and Management Category of the DNW system.
- **Continuous verification monitoring**. Ongoing verification of system performance using sensors for the continuous observation of selected parameters, including surrogate parameters correlated with pathogen LRT requirements.

Field verification is conducted once the system is built (often during the commissioning of the DNW system), and continuous verification monitoring is conducted to ensure proper performance during normal operations. A performance monitoring plan for a non-potable water system may include validation testing, field verification, and/or continuous verification monitoring.

ES.7 Storage, Distribution, and Use of Water from Decentralized Non-Potable Water Systems

The proper storage and distribution of treated water must be addressed thoroughly and managed carefully. After treatment, it is necessary to prevent the growth of opportunistic pathogens like *Legionella* and the contamination of non-potable water by sewage or the release of lead and copper (which causes toxicity). The Panel provided a recommended set of management practices in this report to help prevent such issues. The PAR should clearly state how to implement such management practices specific to the individual DNW system.

ES.8 Permitting and Reports

The process recommended to receive regulatory approval for a DNW system includes several reports, as listed in Table ES-2. Routine reporting will be required upon project approval.

Table ES-2: Reports Submitted and Issued as Part of the Process to Approve a Decentralized Non-Potable Water System

Action	Report/Document	Description
Submitted	Draft Permit Application Report	Includes proposed uses and treatment (if this step is allowed by the jurisdiction's process and is justified by the complexity of the project).
	Final Permit Application Report	Includes plans and specifications, a commissioning plan, and an operation and maintenance plan.
	Facility Commissioning Report	Includes results from field verification and a final monitoring plan.
Issued	Permit decision document	
	Monitoring requirements	

ES.8.1 Permit Application Report

A Permit Application Report (PAR) should be prepared once the DNW system has been designed and the RME identified (see Steps 1 through 3 in Figure ES-1). The purpose of the PAR is to describe the project and identify how it will comply with each regulatory requirement of the controlling jurisdiction(s), providing regulatory agencies with the information needed to evaluate and permit the project. The scope of the PAR will be dictated by the regulatory requirements for each specific type of project and should be based on the Management Category (as delineated in Table ES-1). As such, all recommended components of a PAR may need to be addressed for Management Category 3 projects, whereas less information would be needed for Management Category 1 projects.

RECOMMENDED COMPONENTS OF A PERMIT APPLICATION REPORT (PAR)

- Responsible management entity.
- Project overview.
- Relevant regulations.
- Water source(s).
- Treatment processes.
- Reliability.
- Water uses.
- Cross-connection control.
- Water quality and $\log_{10}$ reduction value monitoring.
- Facility commissioning plan.
- Operation and maintenance plan.
- Provisions for water quality exceedances, power outages, spills, and other emergencies.

ES.8.2 Commissioning Report

Upon completion of commissioning activities, it is recommended that a report be submitted presenting the results of the facility commissioning demonstration, including field verification (when required). The report should identify 1) any deviations from the commissioning plan and/or effectiveness of treatment and 2) situations that resulted in out-of-specification performance, as well as characterize any water diversions or other actions taken to remain in compliance with permit requirements. A final monitoring plan should be included that specifies the criteria for defining out-of-specification performance of unit processes.

ES.8.3 Routine and Incident Reporting

After a DNW system is operational, routine and incident reporting should be required by the regulatory authority. Compliance monitoring and reporting should be conducted to track relevant control targets, with reports submitted once per year at minimum. Routine reports should include all information necessary for determining compliance with the appropriate requirements depending on the type of project, including:

- Results of verification monitoring and calculations.
- Water quality analyses.
- Flow monitoring.
- Cross-connection tests and inspections.
- Significant maintenance activities.
- Treatment modifications.
- Water quality exceedances.
- Outages (including reasons and durations).

In addition to routine reporting, violations and incidents that may indicate a risk to the public (e.g., suspected cross-connections, treatment bypasses, or reports of illness) should be reported immediately.

CHAPTER 1

Introduction

1.1 Overview of Decentralized Non-Potable Water Systems

To address growing pressures on water supplies (such as increased demand, climate change, and impairments to water quality), water managers are seeking new approaches to conserve water and develop alternative water supplies. Municipalities are interested in using more local water supplies to minimize the import and export of water, use energy more efficiently, and increase the sustainability and resiliency of water resources.

Many approaches to water conservation (e.g., using reclaimed water and encouraging indoor and outdoor water conservation practices) are now widely accepted. One approach gaining interest is the use of onsite water sources to meet non-potable demands (NRC, 2016). This report refers to these projects as “Decentralized Non-Potable Water (DNW) Systems”, defined as systems in which local sources of water (e.g., roof runoff, stormwater, graywater, and wastewater) are collected, treated, and used for non-potable applications at the building, neighborhood, and/or district scale, generally at a location near the point of generation of the source of water.

Nationwide, many communities have developed programs to promote or guide the use of onsite water sources for non-potable applications (NRC, 2015; SFPUC, 2015; Los Angeles County Department of Public Health, 2016). For example, many states allow the use of roof runoff or graywater in single-owner occupied residences. In addition, there are large-scale commercial or multi-residential buildings where sources of water like roof runoff, graywater, or domestic wastewater are collected, treated, and distributed within and around the building for non-potable uses, such as toilet flushing and/or landscape irrigation (NRC, 2016; SFPUC, 2016; Epstein, 2008). DNW systems can offer advantages to centralized wastewater reuse systems (including lower capacity requirements for pump and collection systems) and could be particularly useful in areas where population growth is high and existing systems are near capacity (Woods et al., 2013). DNW systems also offer a local water supply without extensive infrastructure.

Drivers for DNW systems include the following:

- Developing “green” (i.e., sustainable and resource-efficient) buildings.[3]
- Meeting certifications for Leadership in Energy and Environmental Design (LEED).[4]
- Reducing demand on local water resources and infrastructure.
- Increasing the reliability and resiliency of water supplies.
- Reducing energy consumption.
- Reducing the discharge of pollutants to sewers and receiving water bodies.
- Increasing resiliency to catastrophes like major seismic or flooding events.

[3] For additional information: https://archive.epa.gov/greenbuilding/web/html/ (accessed 10/28/2016).

[4] For additional information: http://www.usgbc.org/LEED/ (accessed 10/28/2016).

While some cities (e.g., San Francisco, Santa Monica, Los Angeles, and New York) already have DNW systems in place, widespread adoption will be more feasible once guidance is provided on how to develop such programs. Many states and cities have adopted regulations to allow single-residence use of untreated graywater for irrigation through subsurface systems (i.e., below soil or landscape cover) (NRC, 2016), and public agencies that allow this practice generally are comfortable with the current permitting procedures in place. Many agencies, however, have not allowed DNW Systems for higher-exposure scenarios (e.g., indoor use of alternative water sources, water distributed to a large number of users). Some topics to address include: 1) performance standards that must be met by DNW systems for end uses in which human contact is likely and/or possible, and 2) measures to verify the long-term performance of a DNW system is adequately protective of public health.

The purpose of this report is to provide information and guidance through a risk-based framework to help state and local health departments develop DNW systems that are adequately protective of public health.

The Panel provided guidance in this report on regulating and designing DNW systems for multi-residential, commercial, mixed-use buildings, and district-scale systems. Source waters addressed include blackwater, graywater, domestic wastewater, roof runoff, stormwater, condensate, and foundation water. The Panel considered only non-potable end uses (i.e., toilet flushing, clothes washing, unrestricted-access irrigation, dust suppression, and cooling towers) because these uses represent the main range of expected exposures. Pathogen datasets exist for the source waters considered in this report. The principles used to establish a framework for these end uses could be adapted over time to address other source waters and end uses or to include emerging science on quantitative microbial risk assessment (QMRA).

OPTIONS CONSIDERED IN THIS REPORT

Design Scale	Source Waters	End Uses (Non-Potable Only)
• Multi-residential	• Blackwater	• Toilet flushing
• Commercial	• Greywater	• Clothes washing
• Mixed-use buildings	• Domestic wastewater	• Unrestricted-access irrigation
• District-scale systems	• Roof runoff	• Dust suppression
	• Stormwater	• Cooling towers
	• Condensate	
	• Foundation water	

1.2 Water Sources for Decentralized Non-Potable Water Systems

DNW systems can use various sources of water, as described in Table 1-1. The quality of these sources varies substantially, and treatment for each source will depend on the quality and end use of that water.

Table 1-1: Potential Water Sources for Decentralized Non-Potable Water Systems

Water Source	Definition of Term as Used in this Report
Blackwater	Wastewater originating from toilets and/or kitchen sources (i.e., kitchen sinks and dishwashers).
Graywater	Wastewater collected from non-blackwater sources, such as bathroom sinks, showers, bathtubs, clothes washers, and laundry sinks.
Wastewater	Water that is collected from combined graywater and blackwater sources, also known as sewage.
Roof Runoff	Precipitation from rain or snowmelt events collected directly off a roof surface that is not subject to frequent public access.
Stormwater	Precipitation runoff from rain or snowmelt events that flows over land and/or impervious surfaces (e.g., streets, parking lots, and rooftops). Runoff from roofs with frequent public access is defined herein as stormwater.
Condensate	Water vapor that is converted to a liquid and collected, the most common source in buildings being air conditioning, refrigeration, and steam heating.
Shallow groundwater	Groundwater located near the ground surface in an unconfined aquifer and, therefore, subject to contamination from infiltration of surface sources.
Foundation Water	Shallow groundwater collected from drainage around building foundations or sumps.
Blended Water	Various combinations of water derived originally from blackwater, graywater, wastewater, roof runoff, stormwater, condensate, or foundation water. In many areas, ordinances do not allow the combination of roof runoff and/or stormwater with wastewater as part of the wastewater collection system due to documented concerns associated with sanitary sewer overflows and/or treatment and hydraulic capacity at the publicly owned treatment works. Blended water, however, is the purposeful aggregation of water for use as a non-potable water supply.

1.3 Scales for Implementing Decentralized Non-Potable Water Systems

DNW systems can include systems implemented in individual buildings, as well as the district- and neighborhood-scale. By definition, “building scale” could include single-owner occupied, multi-residential, commercial, and/or mixed-use buildings. Scale is an important consideration for regulating and permitting DNW systems due to the risk of exposure in delivered water.

When graywater or wastewater is generated and used in a single-owner occupied residence, the pathogen load in that water both: 1) originates from people in that residence; and 2) affects people in that residence. Because many pathways exist for exposure to pathogens of which the sources are residents in a single-residence home, non-potable water in a toilet or laundry machine does not serve as the sole pathway for transmitting pathogens (Maimon et al., 2010; NRC, 2016; Ashbolt, 2016).

When water is collected from and/or distributed to multiple residences or users in a commercial building, the potential exists for more types of pathogens to be present (due to the increased number of water users) and transported to end users of the water. Exposures to pathogens in a multi-user building are different and higher than those from single residences (i.e., sourced from residents) due to several factors (e.g., more users, longer lengths of pipe, longer residence time of the water in pipes, more interconnections, and higher likelihood of cross-connection). Consequently, when DNW systems are installed in multi-user buildings, it is necessary to ensure that the treatment and distribution systems perform reliably.

The focus of this report is on DNW systems in multi-user buildings and at the district-scale, where guidance is needed to ensure that systems are designed, constructed, operated, maintained, and monitored to consistently produce and deliver water that is safe for its intended purpose.

1.4 Limitations with Current Regulations for Decentralized Non-Potable Water Systems

Currently, national standards or guidelines for DNW systems are not available in the United States. The responsibility for developing regulations and standards for DNW systems has been left to individual states and local agency health departments and utilities thus far. At present, the most common and widely accepted approaches to DNW systems include the beneficial use of graywater and roof runoff at the single-residence scale for irrigation and toilet flushing. These water sources are accepted by the public for household uses and are perceived as low-risk because they rely on source waters that arguably contain fewer waterborne pathogens and because exposures are small and limited to homeowners (who are the source of the water). Most states allow the single residential use of roof runoff and graywater based on the application of best management practices for these systems. But as DNW systems become larger than single-residence applications and the potential increases for human contact with source waters (e.g., toilet flushing, spray irrigation) (NRC, 2016), local agencies are concerned about health risks of untreated wastewaters and tend to regulate such applications through various performance-based treatment criteria for source water.

A summary is provided in Sections 1.4.1 to 1.4.4 of current state regulations for DNW systems, highlighting key limitations that illustrate the need for clear and concise guidance based on considerations for adequately protecting public health as the use of these systems increases. Based on the limitation of current regulations, there is a need for the following:

- Risk-based performance guidance appropriate for the water source and end use.
- Consistent approach for: 1) management; 2) guidance for monitoring and enforcement; and 3) permitting and reporting.

1.4.1 Need for Risk-Based Performance Guidance

Several states have developed regulations for flushing toilets with treated graywater (Table A-1 in Appendix A) and adopted plumbing codes that allow such systems through the International Plumbing Code (IPC) or Uniform Plumbing Code (UPC). A recent report by the National Research Council on the beneficial use of stormwater and graywater (NRC, 2016) contains a thorough discussion of current state and local agency regulations and criteria.

The basis for selecting these performance-based criteria is not well documented, and a wide variation exists in criteria for water quality parameters, particularly fecal indicator organisms (FIOs) (see Table A-1 in Appendix A and NRC, 2016). Criteria for FIOs often are based on criteria for other water sources and end uses (e.g., municipal scale reclaimed water or surface water body contact) rather than quantitative risk assessment. In addition, some states set performance criteria for flushing toilets with roof runoff (Table A-2 in Appendix A). These criteria do not vary as widely as those for graywater; however, the criteria differ substantially from those set for indicator organism criteria in graywater, even in the same state. The wide variations set by states in criteria for flushing toilets and urinals with graywater, roof runoff, and stormwater indicates uncertainty amongst the regulatory community, likely a result of the lack of nationally adopted health risk-based guidance.

States such as California, Colorado, and Oregon apply treatment standards as developed by the National Sanitation Foundation (NSF) for evaluating systems against standard water quality parameters, and use such standards for toilet flushing with treated graywater. A health risk-based approach was not applied to develop NSF Standard 350 (NRC, 2016). Specific to onsite water reuse, NSF 350 was developed as a treatment system certification process to establish minimum requirements for the material, design, construction, and performance of residential and commercial water reuse treatment systems with respect to conventional water quality parameters (e.g., biochemical oxygen demand, suspended solids, fecal coliforms), but not specified pathogen reduction or health outcomes. To meet NSF certification, treatment systems must undergo a 26-week testing period during which the system is dosed with synthetic graywater and must meet the water quality standards outlined in NSF 350 (NSF, 2016) (see Table A-3 in Appendix A).

The foundation for the performance-based standards in NSF 350 was a review of current treatment regulations in 1) states where such standards existed and 2) internationally, most of which applied to the municipal use of treated effluent (NRC, 2016). NSF 350 has provided a framework to enable some DNW systems to move forward; however, the basis for these standards may not be consistent with the goal of a DNW system. NSF 350 and similar standards rely on end-point assessments of water quality without considering the input of pathogen loads and performance of unit processes required for the inactivation and/or removal of those pathogens. As a result, NSF 350 end-point water quality criteria can be met even though the $\log_{10}$ reduction of pathogens may not be achieved. The end-point water quality criteria included in NSF 350 for parameters like biochemical oxygen demand and turbidity are strict, and the basis for setting those criteria is not well documented (NRC, 2016). Overall, NSF 350 provides end-point water quality criteria for system performance, but does not provide health-based criteria. Yet, because NSF 350 is one of the only existing resources that state agencies can use for guidance, many states are considering or already have adopted the water quality standards set by NSF 350. These standards were alsoincorporated into Chapter 15 of the 2015 Uniform Plumbing Code (International Association of Plumbing and Mechanical Officials, 2015).

Some agencies considering permits for DNW systems also use California's Title 22 Recycling Criteria to guide the development of performance standards. Title 22 regulations include performance criteria for centralized treated wastewater for indoor and outdoor non-potable applications. These criteria were developed specifically for the use of treated municipal wastewater and do not consider other water sources (e.g., stormwater, graywater, or roof runoff). Criteria included in Title 22 for indicator organisms and disinfection standards (including suggested log_{10}-reductions for viruses) were developed specific to centralized domestic wastewater reuse and are not applicable to decentralized systems or other source waters. In addition, Title 22 was written to address municipally operated systems with onsite laboratories, full-time operators, and management controls associated with long pipe networks. DNW systems are different from centralized systems and have regulatory needs outside the scope of Title 22; therefore, Title 22 is not directly applicable to DNW systems.

Although various performance criteria exist for DNW systems, those criteria are not health risk-based. Therefore, there is a need for guidance on developing performance criteria for DNW systems using a health risk-based approach. A clear understanding of the potential health risks associated with different sources of water and their proposed end uses is needed in order to develop programs that ensure DNW systems are protective of human health and have appropriate monitoring systems.

1.4.2 Need for a Consistent Approach for Management

Regulatory approaches for the operation and ownership of potable water supply systems must be modified to adapt to the unique characteristics of the different scales applicable to DNW systems. Historically, the focus of regulations logically targeted the higher-risk, larger systems that affect more people and have significant negative impacts if they fail to perform as planned. Currently, guidance does not exist that enables a consistent and simple-to-understand approach for managing DNW systems. Having such guidance would prevent system mismanagement and mitigate human health risks that result in failed projects and lack of public trust in DNW systems.

1.4.3 Need for Guidance on Monitoring and Enforcement

An issue with many regulations for DNW systems is that not all include a balanced approach for monitoring and enforcement to ensure DNW systems operate in a consistent manner to protect public health. For this reason, many states do not allow DNW systems in multi-user buildings or district-scale applications. In California, the health departments for the City of San Francisco and County of Los Angeles developed programs for DNW systems that include performance criteria specific to different sources of water and end uses of those waters (SFPUC, 2015; Los Angeles County Department of Public Health, 2016). These programs include approaches for monitoring and reporting in which requirements vary based on 1) the risks associated with the source waters; and 2) human contact associated with end uses. These programs have helped establish a protocol for monitoring and reporting on the performance of DNW systems.

Notably, current monitoring and reporting requirements can be cumbersome and expensive for the owner. In addition, although more frequent sampling and reporting will help identify DNW systems that are regularly out-of-compliance, they will not ensure the delivery of safe water to the end user. For example, some existing requirements for the onsite use of treated wastewater for indoor applications require daily monitoring of indicator organisms (e.g., total coliforms or *E. coli*). Such monitoring can be cost-prohibitive and does not provide real-time data on treatment system performance (which can ensure a rapid response for systems that are out-of-specification in meeting pathogen LRTs).

Frequent monitoring is used to ensure that DNW systems perform as designed (**Table 1-2**). The most effective approach involves continuous monitoring of select water quality parameters serving as surrogates for pathogen LRTs. Such monitoring would involve accessible and reliable online instrumentation correlated with system performance to achieve the desired treatment goals. Guidance is needed to develop a framework for monitoring and reporting on the performance of DNW systems that is both pragmatic and effective in protecting public health.

Table 1-2: Key Monitoring and Reporting Considerations for Decentralized Non-Potable Water Systems

No.	Key Item	Description
1	Validation	Validate unit processes prior to installation. Validation includes an evaluation study conducted using challenge testing with target or surrogate pathogens over a defined range of operating conditions.
2	Monitoring	Use continuous monitoring systems to monitor water quality in real time.
3	Control and automation	Operate systems (including shut down and start up) based on a specific set of monitoring conditions.
4	Alarms	Create automated alarms for appropriate parties using critical malfunction conditions. Characterize these alarms by the degree of response required.
5	Field verification	Manually collect water samples for microbial analysis to check system performance in achieving $\log_{10}$ reduction targets (LRTs). The need and scope of field verification depends on the characteristics of the Decentralized Non-Potable Water System, including complexity and risk.
6	Continuous process verification	Provide ongoing confirmation of system performance using sensors to observe selected parameters on a continuous basis, including surrogate parameters correlated with pathogen LRT requirements.
7	Data	Log and preserve data for a prescribed period and share this data with identified parties. Telemetry systems are used commonly for real-time web-based data monitoring.
8	Reporting	Provide periodic summary reports to the regulator, preferably in electronic format, and include performance verification by a qualified professional.

1.4.4 Need for Consistent Approach to Permitting and Reporting

Guidance is needed on what requirements must be addressed in a permit application. The permit application for a DNW system should describe the project and identify how it will comply with each regulatory requirement of the controlling jurisdiction(s), providing regulatory agencies with the information needed to evaluate and permit the project.

In some states, different authorities and different state or local codes regulate the different source waters used by DNW systems, making it a challenge to develop a single, consistent permitting approach for these projects. In such cases, it may be appropriate to develop a separate DNW system program, similar to that in San Francisco (SFPUC, 2015), where personnel coordinate with the various regulatory authorities responsible for different water sources and local codes. Many obstacles related to the lack of integration between departments in some states can be overcome by creating a program where personnel are designated to communicate amongst different departments and authorities to create a common process that addresses the needs of all these entities.

Reporting for DNW systems needs to be appropriate to the application and should be provided to the regulator in a brief manner, including information about out-of-specification or noncompliance events, as well as appropriate responses to those events.

1.5 Independent Advisory Panel Review Process

An Independent Advisory Panel was organized in 2015 to address the need for guidance on DNW systems. The National Water Research Institute (NWRI) administered this Panel process, which was designed to provide consistent, thorough, and transparent oversight and recommendations, as documented in this report. Members of the Panel have expertise in a range of disciplines relevant to onsite water systems, such as water quality, treatment technology performance, regulatory criteria, and public health. They include professionals from academia, consulting firms and/or independent consultants, and regulatory agencies in the water industry. Short biographies about the Panel members are provided at the end of this report.

PANEL MEMBERS

- *Chair:* Sybil Sharvelle, Ph.D., Associate Professor of Civil and Environmental Engineering, One Water Solutions Institute, Colorado State University (Fort Collins, CO)
- Nicholas Ashbolt, Ph.D., Professor, School of Public Health, University of Alberta (Canada)
- Edward Clerico, P.E., CEO Emeritus, Natural Systems Utilities (Hillsborough, NJ)
- Robert Hultquist, P.E., Environmental Engineering Consultant and California Department of Public Health (Retired) (Berkeley, CA)
- Harold Leverenz, Ph.D., P.E., Project Scientist, University of California at Davis (Davis, CA)
- Adam Olivieri, DrPH, P.E., Vice President, EOA Inc. (Oakland, CA)

1.6 Basis of Developing Guidance for Decentralized Non-Potable Water Systems

The approach provided in this framework can be applied and expanded to multiple sources of water and end uses of interest. It also can serve as a basis to address sources and end uses not discussed in this report. As interest in DNW systems grows, guidance is needed to set appropriate performance criteria and develop an appropriate management structure for monitoring and permitting these systems. Examples of risks that must be managed with DNW systems include treatment process malfunction, cross-connections, unintended exposures to treated or untreated non-potable water, and others.

A key consideration during the development of this risk-based framework was the need to provide a flexible approach that enables the pragmatic design and operation of DNW systems, ensuring the reliable delivery of water that is protective of public health and meets the needs of different communities across the United States. The focus is on multi-user buildings (i.e., multi-residential, commercial, and mixed-use buildings) and district-scale applications; however, the risk-based framework presented herein is applicable across different scales. The source waters addressed include blackwater, graywater, domestic wastewater, roof runoff, stormwater, and foundation water. The Panel considered only non-potable end uses (i.e., toilet flushing, clothes washing, unrestricted access irrigation and dust suppression, and cooling towers); however, the approach can be used for any combination of source water and end use.

Because only non-potable end-uses are addressed, the most important risk is human exposure to pathogens that become airborne or are ingested with small amounts of water. Non-potable water sources also have the potential to include chemical contaminants that may present exposure risks. Chemical exposures, which are a matter of concern for all aspects of water supply and wastewater disposal, are not considered in this framework. Notably, the framework does not include industrial wastewaters, which may pose a higher risk for chemical contaminants than the source waters addressed here. Little is known about chemical contaminants in the source waters discussed in this report, their exposure routes for the end uses, or the potential health impacts they may pose. In addition, the presence and fate of antibiotic resistant bacteria and genes in DNW systems are not well understood; therefore, the framework was developed to address the removal of pathogens, considered the greatest concern to human health in DNW systems.

GUIDANCE PROVIDED IN THIS REPORT

- Performance-based treatment LRTs for pathogen surrogates (to address viral, bacterial, and protozoan pathogens) based on the source water and non-potable end uses for those source waters to deliver the risk benchmark that we accept for both drinking and recreational waters (i.e., a tolerable risk from one infection per 10,000 and one infection per 100 people per year, respectively).
- Design to achieve reduction targets for pathogens.
- Management structure for DNW systems.
- Approach to ensure the system is consistently meeting performance-based criteria.
- Guidance for storage, distribution, and use of water from DNW systems.
- Permitting approach and reporting requirements for DNW systems.

During an expert consultation meeting in Stockholm in 1999, the World Health Organization (WHO) decided to have a harmonized, risk-based approach for all water exposures. At the meeting, the foundations for the water safety plans were further developed, which were first published by WHO for their drinking water guidelines, and soon after for wastewater reuse (WHO, 2004, 2006). Figure 1-1 presents a framework for DNW systems that fits the Water Safety Plan approach promoted by WHO for all water exposures (Fewtrell and Bartram, 2001), whereas Figure 1-2 outlines the overall process for implementing DNW systems as proposed in this framework.

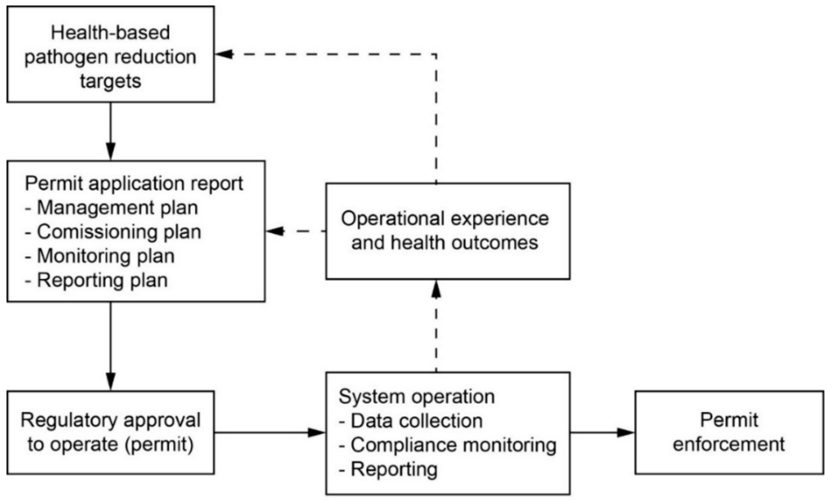

Figure 1-1: Framework for Decentralized Non-Potable Water (DNW) Systems that fits the Water Safety Plan approach promoted by the World Health Organization.
Dashed lines indicate where experiences from DNW systems are used to improve the process.

1. Design

- Select the appropriate $\log_{10}$ reduction target (LRT) for the end use.
- Select the appropriate treatment process train to achieve the LRT.
- Receive approval by a Professional Engineer.

2. Management Plan

- Specify the Responsible Management Entity (RME) Management Category (1 - 3).
- Designate the roles and responsibilities of the RME.

3. Permit Application Report Submission

- Specify the design, RME, assurance of reliability via monitoring, commissioning plan, operations and maintenance (O&M) plan, and plan for managing the distribution system.
- Receive sign-off by a Registered Professional Engineer and approval by the regulatory agency.

4. Construction and Commissioning

- Demonstrate field verification, when required.
- Submit the Commisioning Report (which includes field verification results and the final monitoring plan).

5. Operational Monitoring

- Continuously monitor, at high frequency, surrogate water quality and/or operational parameters correlated to the LRTs.
- Include controls for the production of water that is out-of-compliance.

6. Reporting

- Include violations and incidents.
- Use a format for routine reporting that is simple to review.
- Receive approval and enforcement by the regulatory agency.

Figure 1-2: Proposed framework for implementing Decentralized Non-Potable water systems.

Unlike current standards for DNW systems that often rely on endpoint assessments of water quality, the framework proposed here is a systems-based approach that uses surrogates for treatment process performance in terms of log_{10} reduction of pathogens at critical control points. While the risk-based framework is new for DNW systems, the approach is based on widely accepted practices for potable reuse (both direct and indirect), which subsequently followed drinking water practices. One example of a project that applied the approach proposed in this framework was for three full-scale stormwater treatment and harvesting systems in Melbourne, Australia, where the end use of the water was unrestricted access spray irrigation (Petterson et al., 2016). Australia has developed health risk-based guidelines for the use of non-potable water (NRMMC et al., 2009). The framework shown in Figure 1-2 includes risk-based guidance on estimated LRTs for pathogens, which are addressed in Chapters 3 and 4.

One key to the success of a DNW system is the development of an appropriate management plan for commissioning, monitoring, and reporting, as discussed in Chapter 5. The management plan should be incorporated into a Permit Application Report (PAR) developed by a Registered Professional Engineer or other appropriately trained, licensed professional (Chapter 8).

Appropriate LRTs should be determined for the DNW system (Chapter 3) and unit processes selected to achieve those LRTs (Chapter 4). Due to the limited number of DNW systems in operation, it may not be possible to find off-the-shelf technologies validated with the desired sources of water and unit process configurations. In this case, technology validation is needed to ensure the unit processes achieve the LRTs (Chapter 6). Once the validated unit processes are installed, field verification (including challenge testing with surrogate pathogens) may be required during commissioning, recognizing that field verification could be simplified or eliminated for a specific unit process treatment train that has been verified extensively through similar installations.

Upon successful commissioning, operation will commence and include monitoring. Continuous monitoring is recommended using reliable, accessible, reasonably priced online instrumentation that targets select parameters correlated with system performance to achieve the desired LRTs (Chapter 6). Reporting must be conducted in a simple, user-friendly format that can be reviewed by health agencies (Chapter 8). Violations and incidents should be reported, along with descriptions of how such incidents were addressed.

This framework is designed to be flexible in anticipation that some guidance will change over time based on experience gained in operating DNW systems and advances made in approaches and methodologies to estimate risk-based LRTs.

CHAPTER 2

Risk-Based Management Considerations for Decentralized Non-Potable Water Systems

2.1 Introduction

The first step to implementing onsite water reuse is to determine the appropriate management needs and requirements of the DNW system to ensure the protection of public health. The Panel uses the term Responsible Management Entity (RME) in this report to refer to the entity that must carry out this work. The specific details of RME formation and roles and responsibilities are discussed in Chapter 5, but are considered here as ranging from less to more rigorous in correlation with the associated risks of a particular DNW system.

As the complexity and/or size and customer base of a DNW system increases, the level of regulatory oversight and management requirements increase as well. Regulators need to decide what level of oversight and control is required for different risk exposures within their community. As DNW systems become more complex and variable, they may draw from increasingly contaminated water sources and serve a larger user-base. The potential exposure and risk may increase quickly if the DNW systems serves several owners (which includes piping that crosses between properties) and provides multiple uses of the non-potable water. Even the use of graywater can result in higher pathogen exposure to the end users as compared to potable water and will require treatment mechanisms that require advanced operating skills and more routine attention. Extending the customer base to include multiple buildings or properties (resulting in larger numbers of people using the system on a daily basis) greatly increases the risk of exposure.As DNW systems increase in complexity, it becomes more important for a qualified entity to take full responsibility of system performance.

2.2 Representative Examples of Management Categories

The Management Categories for DNW systems are defined in Table 2-1. A matrix of risk control and accountability, based on the number of end users and complexity of the system, is provided in Table 2-2. A discussion is provided in Chapter 5 of the various roles, responsibilities, and associated protective measures that should be considered in each Management Category. As shown in Figure 2-1, the Management Category might be selected based on the following: 1) proposed usage characteristics of the system; 2) number of people it is likely to serve; 3) complexity of the treatment process; and (4) likelihood of exposure to human pathogens.

Notably, these Management Categories are intended to guide the level of management for a DNW system, but are loosely defined. It is the responsibility of the regulating authority to decide how a DNW system fits within these three Management Categories. This approach is expanded in Table 2-3 with examples of different system configurations and descriptions of appropriate management and regulatory approaches based on the Management Categories, which are derived from the following factors: 1) the number of exposed individuals; 2) source of water and potential for human fecal contamination; and 3) level and type of human exposure.

Table 2-1: Risk-Based Management Categories for Decentralized Non-Potable Water Systems

Management Category	Definition of Category
1	• Lowest user population. • Non-potable water sources with the lowest concentrations of pathogens. • Non-potable water uses with the lowest human exposure. • Treatment mechanisms that are simple to operate and maintain.
2	• Some increase in the number of persons exposed, but strong mitigating factors achieved through combinations of small user populations. • Non-potable water sources with the lowest concentrations of pathogens. • Non-potable water uses with low human exposure. • Treatment mechanisms that are simple to operate and maintain.
3	• More exposure risk due to the combinations of increased user populations. • Non-potable water sources with higher concentrations of pathogens. • Non-potable water uses with increased likelihoods of exposure. • More complex treatment mechanisms that require rigorous operation and maintenance.

Table 2-2: Risk Control and Accountability Matrix for the Risk-Based Management Categories

Management category		
1	**2**	**3**
Low	**Risk characterization** ↔	High
Few users, no public access	**Pathogen risk** ↔	Many users, public access
Simple devices and/or processes	**Process malfunction risk** ↔	Complex devices and/or processes
	Regulatory oversight	
System owner is fully responsible and accepts all liability for system performance. Local regulatory authority may provide owner education and registration of system as per thier specific regulations.	System owner retains system responsibility and complies with local regulatory authority's additional quality control via a combination of manufacturer approval/certification, O&M manual, installation inspection, system permit and some degree of performance monitoring.	Prequalified RME accepts all performance responsibility. Regulator qualifies the RME, issues permit, reviews performance report and certifications, performs periodic inspections and enforces permit compliance.
	RME requirements	
Private owner serves as RME and complies with regulatory authority's requirements.	Private owner as RME fully complies with local regulatory authority's requirements.	RME provides financial security, assumes full performance accountability, responsibilty for permit compliance, routine reporting and certification.

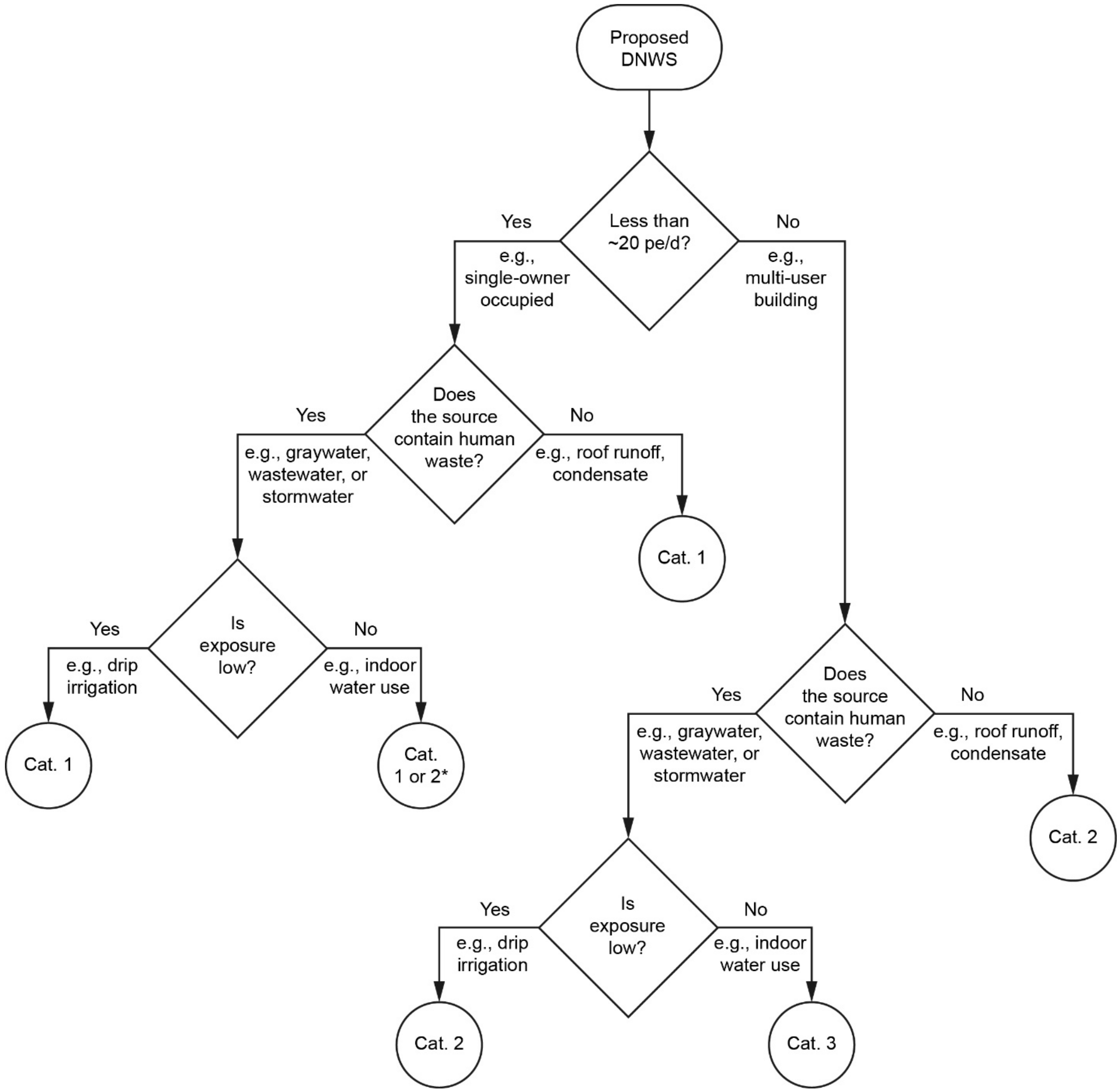

Figure 2-1: Guidance to specify Management Category.
("pe/d" refers to "people exposed per day" to non-potable water)

*Note: Some simply designed single-owner occupied indoor reuse systems (e.g., graywater) could be classified as Management Category 1, while others (e.g., wastewater reuse) would be classified as Management Category 2.

Table 2-3: Examples of Risk-Based Considerations for Identifying the Management Category of the Decentralized Non-Potable Water System

	Example	Number of Persons Exposed	Likelihood of Malfunction	Management Category and Considerations	Health Agency Role
1	Single-owner occupied system using roof runoff for irrigation	Small user base (<~20 pe/d[1])	Low - low pathogen content - simple process	Management Category 1 - Building owner serves as the Responsible Management Entity (RME) with full responsibility	Provides educational information to building owners and issues permit
2	Single-owner occupied system using graywater for toilet flushing and irrigation	Small user base (<~20 pe/d[1])	Moderate - equipment maintenance required	Management Category 1 - Building owner serves as RME with full responsibility	Requires manufacturer certification of equipment, operation and maintenance (O&M) manual and issues permit
3	Single-owner occupied system using roof runoff and treated wastewater for toilet flushing, laundry, and subsurface irrigation	Small user base (<~20 pe/d[1])	Considerable - complex equipment requires routine O&M by trained staff	Management Category 2 - Independent registered service agent provides O&M	Registers/licenses service agent, defines reporting of data and issues permit
4	Multi-user building with roof runoff system for irrigation	Moderate user base (20-100 pe/d[1])	Low - low pathogen content - simple process	Management Category 1- Building owner or HOA serves as RME with full responsibility	Registers/licenses service agent, defines performance reporting and issues permit
5	Multi-user system using treated graywater for toilet flushing and irrigation	Large user base (100-1,000 pe/d[1])	Moderate - equipment and distribution system requires trained O&M staff oversight	Management Category 3 - Qualified full service RME with financial security and routine reporting	Establishes RME qualifications, ensures financial guaranty, requires data reporting, and issues permit
6	District/multi-user system serving mixed uses, collecting roof runoff and treated wastewater sources for toilet flushing, laundry, cooling, and irrigation	Large user base (100-5,000 pe/d[1])	Significant - Complex process and distribution system requiring skilled O&M	Management Category 3 - Qualified full service RME with financial security and routine reporting	Establishes RME qualifications, ensures financial guaranty, requires data reporting, and issues permit

[1] pe/d = People exposed per day to the non-potable water. The <~20 pe/d figure is a rough estimate of likely exposures in a single residency with consideration of visitors to the residence.

In assigning the Management Category, the number of persons exposed should be considered rather than the number of occupants in the building. When considering the risks associated with DNW systems, the number of persons that could be exposed to the non-potable water is the important consideration. One could use a similar approach to that outlined in Table 2-1 and Table 2-2 to determine the appropriate Management Category level for a DNW system that may differ from those considered in Figure 2-1. As demonstrated in Table 2-2, commensurate levels of performance guarantees and regulatory oversight with management risk/benefit considerations should parallel the science-based risk/benefit facts.

Regulators must consider how to adopt the principles of risk management to their states or specific communities. Non-potable water systems provide safe, affordable options that conserve and supplement water supplies. The key is implementing the proper management and oversight to properly design, install, and operate these systems.

Some systems serve a small user-base and employ simple mechanisms to handle relatively clean sources of non-potable water, such as roof runoff or condensate. These systems do not require a high level of oversight because 1) homeowners can easily manage them and 2) the risk to public health is low; therefore, they fall outside the scope of this report. Nevertheless, regulators may want to provide educational materials to ensure homeowners are well informed, understand the importance of system performance, and know where to seek help, if needed. In such cases, the building owner serves as the RME in all capacities (i.e., finance, performance, and use) and retains all responsibility. On the opposite end of the spectrum, larger systems serve a wide user-base, have complex mechanisms, and require diligent management. Consequently, regulators must ensure qualified entities are assigned the appropriate responsibilities and held accountable for DNW system management. A discussion is included in Chapter 5 of possible combinations of roles and responsibilities, along with what considerations may arise with each type of system, regardless of size or complexity.

As shown in Figure 2-1, it is possible to modify the three Management Categories to fit a particular community's perspective and goals for risk sharing and level of oversight. Given the similarities in personal and public exposures to waterborne pathogens, the current regulatory controls placed upon private and public swimming pools can provide a useful analogy for gauging the appropriate degree of regulatory oversight and control for DNW systems. The exposure risk for DNW systems would be less than that for many swimming pools; however, swimming pool management is a well-understood discipline, and water quality controls for pools are simple compared to those for DNW systems (pools can be closed quickly if a problem is discovered, and the source water is a potable supply). The novelty and lack of familiarity with DNW systems creates a steep learning curve, requiring more initial support.

2.3 Decentralized Non-Potable Water System Reliability Features for Alternative Management Categories

Ensuring the reliability of DNW systems is critical for reducing the potential for process malfunctions and reducing risks if process malfunctions occur. For example, automated systems can shut down or take the process offline before delivering water for a reuse application. With appropriate management and maintenance, the risks associated with DNW systems can be minimized through robust design, operation, and monitoring. Many design and control features for DNW systems can enhance reliability; however, the applicability of such features varies across Management Categories. See Table 2-4 for examples of process design and control features that can enhance reliability.

Table 2-4: Examples of Process Design and Control Features to Enhance the Reliability of a Water System and Applicable Management Category

Feature	Description	Management Category 1[a]	2	3
Alarm systems	Automated notification that the water system requires attention or service.		✓	✓
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 non-potable use.			✓
Management barriers	Policy and maintenance plans that provide guidance for staff of the Responsible Management Entity (RME) to make critical decisions.		✓	✓
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 unit processes that support critical control points. Operational control points are not used specifically for pathogen control.		✓	✓
Performance monitoring (continuous)	Monitoring systems for unit processes that provide control for pathogens identified in the risk assessment and, therefore, include the provision of $\log_{10}$ reduction credits.		✓	✓
Process resiliency	Use of treatment processes that can be restored to operation rapidly following a process failure.			✓
Process robustness	Removal of a broad spectrum of constituents using a combination of technologies.			✓
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.		✓	✓
Redundant processes	The use of processes in parallel or series, such that one or more processes can be taken offline without affecting pathogen removal performance. Provides removal of a specific constituent using more than one unit process.			✓

Feature	Description	Management Category		
		1[a]	2	3
Reliability of individual processes	The use of processes that are inherently stable with respect to seasonal changes, power outages, and other variations will enhance overall performance.	✓	✓	✓
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 by the RME.		✓	✓
Sensors and instrumentation for process monitoring	Sensors for continuous monitoring and assurance that pathogen log_{10} reduction targets are met is an essential feature of a Decentralized Non-Potable Water System.		✓	✓
Source control measures	Overall reliability can be enhanced by eliminating constituents (e.g., biocides) that could have a negative impact on the treatment system.	✓	✓	✓
Technical barriers	The use of unit process treatment barriers that can be credited with treatment performance.		✓	✓

[a] Management Category 1 systems are presented for comparison only and may be subject to considerations beyond the scope of this report.

CHAPTER 3

Risk-Based Pathogen Reduction Targets

3.1 Introduction

In this chapter, the Panel provided examples of risk-based[5] fecal pathogen $\log_{10}$ reduction targets (LRTs) for local, non-potable uses of a variety of source waters (i.e., domestic wastewater, local graywater, blackwater, roof runoff, and stormwater) for different end-uses (see Figure 3-1 and Table 3-1). The Panel used Quantitative Microbial Risk Assessments (QMRAs) to derive the pathogen reduction targets (Petterson and Ashbolt, 2016; WHO, 2016) (see Schoen et al., 2017; Jahne et al., 2016 for details). QMRA is a scientific approach to estimate the potential human health risks associated with exposure to microbial hazards (i.e., human pathogenic viruses, bacteria, and protozoa) (Haas et al., 1999). As discussed in this chapter, the Panel developed the estimated LRTs based on a range of tolerable risk used by the U.S. Environmental Protection Agency (U.S. EPA) for both voluntary and involuntary exposures. Using QMRA, the WHO and Australian government established risk-based LRTs of fecal pathogens for a limited number of non-potable applications for stormwater, roof runoff, and municipal wastewater (NRMMC et al., 2006, 2008, 2009; WHO, 2006a,b).

A recent review of published risk-based pathogen reduction targets for local non-potable reuse indicated the need for further QMRA to address questions of scale, sporadic pathogen occurrence, and the impacts of exposures resulting from misuse or failure (Schoen and Garland, 2015). The Panel based the QMRA on a probabilistic modeling approach that addresses the likely variability in pathogen concentrations. To clarify, it is not a deterministic point-estimate approach for worst-case and/or best-case scenarios. Rather, it is a stochastic approach used to estimate probability distributions of infection based on the variability associated with pathogen concentration, aimed at attaining a specified tolerable risk level. Consequently, from a risk-based perspective for non-single residential uses, the size of the system does not affect the estimated LRTs, assuming proper design, construction, operation, and maintenance. In summary, the probabilistic QMRA (further described in **Appendix B**) accounted for:

- Different ranges of end users, each with a unique set of daily exposures (e.g., a small fraction of the total population of users exposed to a cross-connection event).
- Variation in pathogen density.
- Sporadic pathogen occurrence.

In this chapter, risk-based pathogen reduction targets are presented for non-potable uses of onsite waters, and the probabilistic QMRA approach is used to estimate these targets. The Panel did not address fire suppression and condensate collection systems, given the unknown deterioration and growth of opportunistic pathogens in these systems (discussed further in Chapter 7).

[5] The risk target used in this report is the annual one infection per 10,000 (10^{-4} risk) reported by the U.S. Environmental Protection Agency (U.S. EPA) as the target pathogen risk in the development of drinking water regulations, and to address voluntary exposures, 10^{-2} infection per year target was used, which is based on the U.S. EPA's recreational water criteria of 10^{-2} illness/exposure (U.S. EPA, 2012).

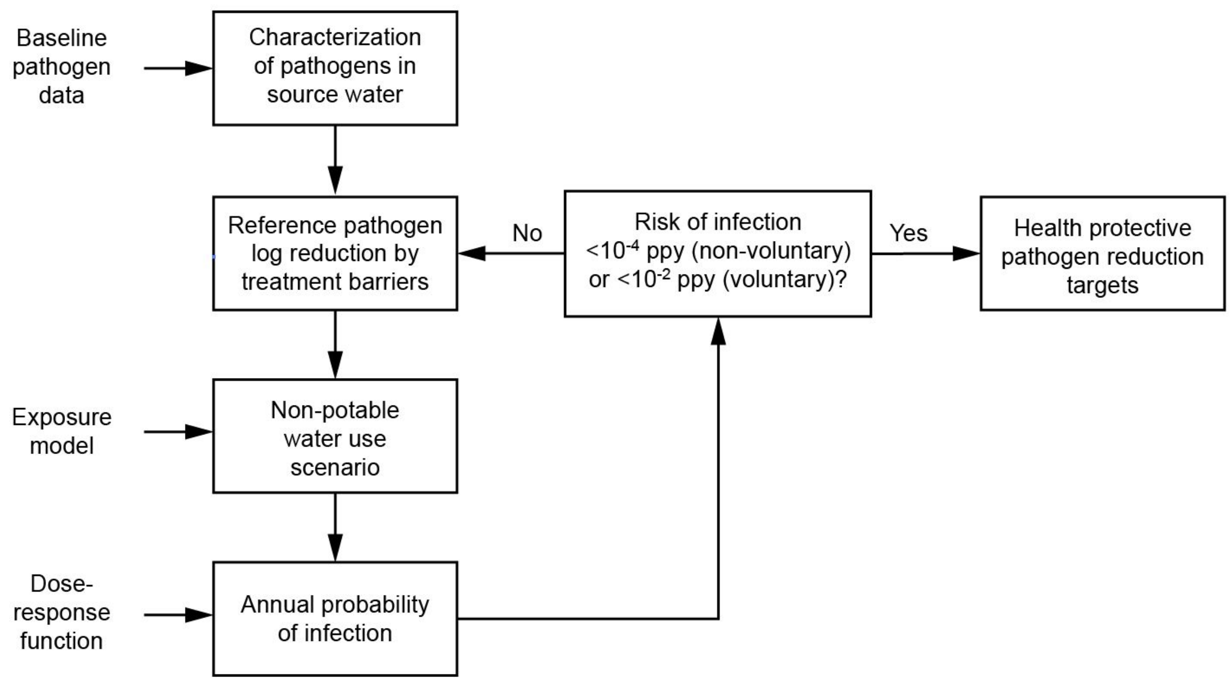

Figure 3-1: Approach used by the World Health Organization (WHO) to describe pathogen reduction targets (Petterson and Ashbolt, 2016). For this report, the health targets were based on annual infections rather than on Disability Adjusted Life Year (DALYs) as used by WHO.
Note- that "ppy" stands for "per person per year."

Table 3-1: Non-Potable Uses and Characteristics

Activity[a]	Type	Ingestion (liter) per activity	Uses per year	Fraction of population	Reference
Toilet flush water	Ingestion of spray	0.00001	1100	1	(NRMMC et al., 2006)
Clothes washing	Ingestion of spray	0.00001	100	1	(NRMMC et al., 2006)
Unrestricted irrigation and dust suppression	Ingestion of sprays	0.001	50	1	(NRMMC et al., 2006)
Cross connection of non-potable water with potable water	Ingestion	2[b]	1	0.1	(NRMMC et al., 2006)

[a] Condensate used from Heating, Ventilation, and Air Conditioning (HVAC) systems is not considered to present enteric pathogen risks, but rather water-based pathogen risks by inhalation exposure and its management is described in Chapter 7.

[b] Upper likely direct ingestion per day if accidently considered drinking water or if cross-connected to drinking water (see Schoen et al., 2017 for log_{10} reduction targets without cross-connection or accidental ingestion).

3.2 Health Benchmarks and Risk-Based Targets

The use of risk-based pathogen reduction targets is an attempt to achieve a specific level of health protection for consumers, typically expressed as a tolerable burden of disease. A Disability Adjusted Life Year (DALY) is the sum of years of life lost by premature mortality and years lived with disability (Murray and Acharya, 1997). Another approach involves using a tolerable level of infection or illness risk per person per year (ppy). For potable and non-potable water consumption, WHO suggests that the tolerable burden of disease corresponds roughly to an infection risk of approximately 10^{-3} ppy for Rotavirus or *Cryptosporidium* and 10^{-4} ppy for *Campylobacter* (WHO, 2006a,b; NRMMC et al., 2009).

For the purposes of this report, the health endpoint is assumed to be infection. In this specific case, the U.S. EPA health risk assumption for illness for water recreation (i.e., full body contact) of 10^{-2} has been utilized in this report as a potential higher (less stringent goal) level of infection risk (U.S. EPA, 2012). Please note that a key distinction previously noted for considering the range of acceptable risk goals is whether exposure is voluntary or involuntary. Further, the Panel considered the risk assumption relied on by U.S. EPA in setting drinking water standards under the SDWA (i.e., 10^{-4}) which could incorporate cost and feasibility.

3.3 Non-Potable Exposures

The non-potable uses addressed by the health-protective pathogen reduction targets are included in Table 3-1, along with the likely volumes of water ingested during each activity, anticipated frequency of use, and fraction of the population likely to be exposed. Overall, variation in the volumes ingested or exposures (e.g., to toilet flush aerosols versus hand touch to toilet water or to reclaimed waters used in clothes washing) had less impact than the natural variation in pathogen concentrations. The Panel therefore combined end uses into the following two plausible sets of activities:

- **Unrestricted irrigation**. Ornamental plant (non-food) irrigation and dust suppression.
- **Indoor uses**. Toilet flush water, clothes washing, and rare accidental cross connection with drinking water or direct ingestion of treated non-potable wastewater.

Uncertainty in exposure volumes and frequencies are further described in Appendix B. Other non-potable water uses not directly addressed by specifying LRTs include cooling water make-up and water for fire suppression, as the pathogen risks associated with these uses are controlled by best management practices. The reason is that greater microbial risks from these water uses are likely to result from not controlling the growth of water-based pathogens (e.g., *Legionella pneumophila*, *Pseudomonas aeruginosa,* and non-tuberculous mycobacteria) that may proliferate in stagnant piped water (see Chapter 7 on the storage, distribution, and use of DNW systems).

3.4 Onsite-Generated Waters

The focus of this report is on graywater, roof runoff, stormwater, and domestic wastewater. When these onsite sources are blended, the most contaminated source with respect to human-infectious pathogens (i.e., not necessarily the largest by volume) should be assumed to dominate selection of the LRTs. That is, the LRTs for the highest risk source should be used: the risk of domestic wastewater is greater than the risk of graywater, which is greater than the risk of stormwater, which is greater than the risk of roof runoff.

3.5 Reference Pathogens

Reference pathogens represent classes of hazards with potential adverse health impacts that address the behaviors of broadly related microbial groups (e.g., Norovirus for enteric viruses, *Campylobacter* for enteric bacteria, and *Cryptosporidium* for parasitic protozoa). For the source waters listed in Section 3.4, possible reference hazards include enteric pathogens resulting from human or animal fecal contamination. The Panel did not consider LRTs for opportunistic pathogens (e.g., *Legionella pneumophila* and others that may cause skin or lung infections) that may grow within the collection and distribution systems, due to the lack of quantitative information for collection systems. Rather, opportunistic pathogens were considered best controlled by post-treatment management procedures in storage and distribution, as described in Chapter 7.

The Panel reviewed and summarized relevant pathogen concentrations from key resources for blackwater and graywater (WHO, 2006a,b), stormwater (NRMMC, 2009), and roof-harvested water (Chapman et al., 2008). Starting with a screening-level risk assessment, the Panel initially considered a number of human pathogenic viruses, bacteria, and parasitic protozoa resulting from human or animal fecal contamination (Table 3-2). After careful consideration and assessment, the Panel selected final reference pathogens for each combination of source water and end use based on the reference pathogen group dominating risk (see Table B-1 in Appendix B for list of reference pathogens used and their dose-response models).

Table 3-2: Possible Reference Pathogens for Different Water Sources[a]

Pathogen group	Domestic Wastewater	Graywater	Stormwater	Roof Runoff[a]
Enteric viruses	✓	✓	✓	
Enteric bacteria	✓	✓	✓	✓
Parasitic protozoa	✓	✓	✓	✓

[a] When data from the United States was not available to estimate pathogen $\log_{10}$-reductions, the Panel established reference pathogens for: 1) graywater pathogens by using data on pathogen infection prevalence and excretion data; 2) stormwater by the dilution of domestic raw sewage by tenfold and one thousand-fold; and 3) roof runoff by fecal indicators estimating animal fecal loads and assumed pathogens in seagull excreta. Water-based pathogens that may grow post-treatment, such as *Legionella pneumophila*, are not included here; rather, they are addressed by the best management practices described in Chapter 7.

3.6 Characterizing Pathogens in Waters

The recommended $\log_{10}$ pathogen reduction targets are based on pathogen characterizations that account for variability in pathogen density over time and the possibility of sporadic pathogen occurrence (Section B2 in Appendix B). For detailed information about characterizing pathogens in the waters, refer to Schoen et al. (2017) and Jahne et al. (2016).

The Panel estimated pathogen densities in waters using multiple techniques, depending on the type of information available for each source of water. Pathogen observations were used, when available, to characterize pathogen density and occurrence.

CHARACTERIZATION OF PATHOGEN DENSITY AND OCCURRENCE

- **For roof runoff water,** the Panel assumed no human fecal input and estimated pathogen densities from the likely mass of animal feces present estimated by fecal indicators (known as the Animal Feces Approach; Schoen et al. , 2017).
- **For stormwater,** limited pathogen densities were available. Hence, the Panel assumed fecal contamination was human-derived [although it is more likely derived from domestic animals that yield lower concentrations of human-infectious pathogens; however, even small fractions of sewage provide the dominant pathogen concentrations of importance (Schoen and Ashbolt, 2010). The Panel estimated pathogen densities from the fraction of municipal wastewater potentially present (known as the Dilution of Municipal Wastewater Approach).
- **For graywater,** sufficient pathogen density data were not available; hence, the Panel assumed that the fecal contamination was human-derived, and modeled pathogen densities using epidemiological data of pathogen occurrence in the community (known as the Epidemiological Data Approach).

3.7 Pathogen Reduction Targets

The ninety-fifth percentile $\log_{10}$ pathogen reduction targets (LRT_{95}) for each non-potable use scenario are presented in Table 3-3 for healthy adults (based on available dose-response data; see Appendix B), given the 10^{-4} and 10^{-2} ppy risk benchmarks. If a system can maintain this level of treatment performance at all times, then the predicted probability of infection across the population will be *less than* the benchmark for each pathogen 95% of the time. For water with a combination of pathogens, the predicted infection rate across the population will be *greater than* the benchmark. Because these estimates are not precise enough to consider multiple pathogens, the Panel addressed the three classes of enteric pathogens (see Table 3-2) with the most influential reference pathogen from each class (listed in Table B-1 in Appendix B), as recommended and used by WHO (2016).

See Table 3-3 for the results of municipal wastewater, graywater, stormwater with a low dilution of sewage (10^{-1}) and moderate dilution of sewage (10^{-3}), and roof water. These two levels of sewage dilution bound the likely range of sewage contamination in urban stormwater, which is highly variable but poorly defined for pathogens (Chong et al*.,* 2013; Nshimyimana et al., 2014). Based on experience with stormwater in urban environments, some sewage contamination is likely (i.e., at least 10^{-3} dilution of raw sewage). As little as 10^{-1} dilution of raw sewage is possible with a chronic sewer leak or sewer overflow into stormwater. The recommended roof water LRT_{95} reductions, which are the most uncertain, are based on limited available data (e.g., no parasitic protozoa data). Refer to Schoen et al. (2017) for a full discussion of the results.

Table 3-3: Ninety-Fifth Percentile Log_{10} Pathogen Reductions Targets (LRT_{95}) to Meet 10^{-4} (infection) or 10^{-2} (infection) ppy Benchmarks for Healthy Adults[a]

Water Use Scenario	Log_{10} Reduction Targets for 10^{-4} (10^{-2}) Per Person Per Year Benchmarks[b,i]		
	Enteric Viruses[c]	**Parasitic Protozoa[d]**	**Enteric Bacteria[e]**
Domestic Wastewater or Blackwater			
Unrestricted irrigation	8.0 (6.0)	7.0 (5.0)	6.0 (4.0)
Indoor use[f]	8.5 (6.5)	7.0 (5.0)	6.0 (4.0)
Graywater			
Unrestricted irrigation	5.5 (3.5)	4.5 (2.5)	3.5 (1.5)
Indoor use[g]	6.0 (4.0)	4.5 (2.5)	3.5 (1.5)
Stormwater (10^{-1} Dilution)			
Unrestricted irrigation	5.0 (3.0)	4.5 (2.5)	4.0 (2.0)
Indoor use	5.5 (3.5)	5.5 (3.5)	5.0 (3.0)
Stormwater (10^{-3} Dilution)			
Unrestricted irrigation	3.0 (1.0)	2.5 (0.5)	2.0 (0.0)
Indoor use	3.5 (1.5)	3.5 (1.5)	3.0 (1.0)
Roof Runoff Water[h]			
Unrestricted irrigation	Not applicable	No data	3.5 (1.5)
Indoor use	Not applicable	No data	3.5 (1.5)

[a] Water-based pathogens that may grow post-treatment, such as *Legionella pneumophila*, are addressed by best management practices described in Chapter 7.

[b] Log_{10} Reduction Targets (LRT_{95}) were rounded to the highest 0.5 unit, given probable errors in estimating performance in field experiments. See Schoen et al. (2017) for individual reference pathogen LRT estimates.

[c] Fractional Poisson model was used for Norovirus and compared with Rotavirus or Adenovirus (Schoen et al., 2017) to reach the LRT.

[d] Fractional Poisson model was used for *Cryptosporidium* oocysts and compared with *Giardia* cysts (Schoen et al., 2017) to reach the LRT.

[e] *Campylobacter* and *Salmonella* dose-response models (Schoen et al., 2017) used to select the LRT.

[f] Assumes 10% of the population is exposed to a cross-connection event lasting one day per year.

[g] Based on 1,000 people contributing pathogens to graywater; estimates for fewer numbers of people given in Jahne et al. (2016).

[h] Calculated using the Animal Feces Approach, with seagulls as the selected animal and fecal indicator density in stored Australian rainwater (Chapman et al., 2008).

[i] The calculated LRTs must be achieved 100% of the time so that the health benchmark is met 95% of the time.

3.8 Summary of Approach for Establishing Log_{10} Reduction Targets

The LRT_{95} presented in Table 3-3 were rounded up to the nearest 0.5 unit for the approaches used to address enteric pathogen data relevant to the United States. The category for indoor use accounts for potential cross-connections (i.e., two liters of water ingested each year per person for 10% of the population). The LRT_{95} for toilet flushing without considering cross-connections are from Schoen et al. (2017). In general, domestic wastewater represents the highest-risk source water when freshly produced due to enteric viruses and parasitic protozoa in human excreta; therefore, the dilution of human excreta in graywater and sewage in stormwater resulted in the high LRTs also required for these source waters. The Panel assumed that roof runoff was collected from surfaces lacking human contact, hence the absence of the risk of enteric viruses and (due to a lack of data) human-infectious parasitic protozoa. For blended waters, the LRTs for the highest-risk source water should be used (i.e., in decreasing risk order: domestic wastewater, graywater, stormwater, and roof-harvested water). The information presented in Table 3-3 provide the best estimates of LRT_{95} resulting from a range of specific reference pathogen conditions described in Schoen et al. (2017) and Jahne et al. (2016).

The Panel addressed enteric viruses by considering data on Norovirus, Adenovirus, and Rotavirus. Due to method limitations, Norovirus data represent total genome copies (of infectious and non-infectious) virus particles. The Panel also estimated infectious Adenovirus and Rotavirus reference pathogens to address the likely range of all virus particles being infectious (very unlikely) to only those estimated to infect cells (a probable underestimation of total infectious particles), and used that information to recommend virus log_{10}-reductions.

For parasitic protozoa and viruses, the Panel considered different dose-response relationships, selecting the Fractional Poisson as the most appropriate model for each class of reference pathogen [see Schoen et al. (2017) for a description of the estimated risks by dose-response mode]. In general, the resulting LRT_{95} tabulated are an average of the range of likely log_{10} reduction values (LRVs) and rounded to the nearest 0.5-log_{10} unit, given the even greater uncertainties in estimating pathogen concentrations and dose-response relationships. The 10^{-4} LRT_{95} are similar (when reported) considering median LRTs (not ninety-fifth percentiles) for 10^{-6} DALY benchmarks are reported in the Australian wastewater reuse guidelines (NRMMC et al., 2006; 2009).

For graywater, the Panel investigated the possibility of higher pathogen concentrations resulting from a small number of contributors (such as in a building collection system). Yet, there was no greater level of risk at the ninety-fifth percentile (Jahne et al., 2016), so the Panel chose an average of 1,000 people contributing to the graywater pathogen load, which is consistent with the intent to address multi-user and district-scale DNW systems with this framework. Required LRT_{95} for other scales of graywater reuse systems are provided in the literature (Jahne et al., 2016).

CHAPTER 4

Selecting and Evaluating Unit Operations to Achieve Pathogen Reduction Targets

A well-established and accepted concept in modern drinking water and water reuse practices is to attribute the $\log_{10}$ reduction of pathogen groups to specific technologies that are operated within defined limits,coupled with appropriate control points to demonstrate the proper performance of the technology. Various treatment processes and treatment trains can be used to obtain the LRT for a given combination of source water and end use. As described in Chapter 3, LRTs are based on maintaining treatment performance at the ninety-fifth percentile (LRT_{95}) level.

Most treatment processes likely to be applied in non-potable water systems will be more effective against one pathogen group than another. As a result, $\log_{10}$ reduction values (LRVs) for each process must be considered for each reference pathogen. The purpose of this chapter is to provide background information on example process LRVs observed for alternative treatment process.

Topics Discussed in Chapter 4

- Sources of pathogen $\log_{10}$ reduction data.
- Pathogen reduction by natural and biological processes.
- Pathogen reduction by filtration processes.
- Pathogen reduction by disinfection processes.
- Considerations in analyzing process $\log_{10}$ reduction data.
- Example LRVs derived from various sources.

Monitoring approaches and surrogates used for process challenge testing are described in Chapter 6. Applying unit process $\log_{10}$ reduction data to the evaluation of DNW system treatment trains for meeting LRTs is described in Chapter 9.

4.1 Sources of Log_{10} Reduction Data

LRVs are used to characterize the ability of a treatment unit process to serve as a barrier for pathogens. In the case of novel unit operations where only limited information is available, preliminary LRVs are assigned to treatment unit operations based on the results of similar unit operations, existing technology installations, modeling studies, and/or pilot testing. Testing under the full range of relevant operating conditions and specific to the application under consideration can be used to obtain a validated LRV (VLRV). Sources of $\log_{10}$ reduction data include:

- Technology verification programs.
- Pilot studies conducted at universities or similar test-bed installations.
- Previous regulatory certifications.

- U.S. EPA or NSF testing.
- *In situ* testing.

The regulatory authority will determine what data are permissible for use in assigning LRV credits.

4.2 Pathogen Reduction by Natural and Biological Processes

The inactivation of pathogens in engineered water systems takes place through a number of natural mechanisms, including natural die-off, settling, predation, adsorption, and interception. See Table 4-1 for examples of LRVs for natural and biological treatment processes.

Table 4-1: Observed Values for Pathogen Reduction with Natural and Biological Treatment Processes

Barrier	Example Log_{10} Reduction Values[a]			Key Factors that Impact Log_{10} Reduction Values
	Virus	Protozoa	Bacteria	
Primary settling/septic tank	0.8 (0.5 – 1)	0.5 (0.2 – 1)	0.5 (0.1 – 0.6)	Retention time
Upflow anaerobic sludge blanket/anaerobic filter	0.8 (0.5 – 1)	0.5 (0.2 – 1)	0.5 (0.1 – 0.6)	Retention time
Packed bed filter	1 (1 – 2)	2 (1 – 4)	1 (1 – 1.3)	Hydraulic application rate, dosing frequency, filter bed surface area
Trickling filter	0.5 (0.3 – 1)	0.6 (0.4 – 1)	0.5 (0.2 – 1)	Hydraulic loading rate, filter surface area
Suspended growth reactor/ activated sludge	0.5 (0.5 – 2)	0.5 (0.2 – 1)	1 (1 – 1.7)	Biomass conc., retention time
Pond/lagoon	0.8 (0.5 – 1)	1 (0.7 – 2)	0.5 (0.1 – 0.6)	Retention time, pH
Treatment wetland	0.5 (0.2 – 1)	1.2 (1 – 2)	0.8 (0.5 – 1)	Retention time, packing material
Slow sand filter	2 (2 – 3)	4 (3.9 – 7.1)	2 (0.6 – 5)	Sand effective size, filter ripening, filter-to-waste cycles
Storage pond/reflection pool/water feature	1 (1 – 4)	1 (1 – 3.5)	1 (1 – 3.5)	Retention time, exposure to solar ultraviolet light

[a] Adapted from Petterson et al. (2016); EPHC (2008); Mara and Horan (2003); Harrington et al. (2001).

4.3 Pathogen Reduction by Filtration Processes

The removal of particulate matter, including pathogens, by size exclusion is of interest because filters can serve as a barrier to pathogens in water. Filtration is important because pathogens can be shielded by or embedded in particulate matter, reducing the effectiveness of subsequent inactivation processes. Filtration processes can improve the effectiveness of downstream inactivation by moving particulate matter that would interfere with disinfection. Typical values for pathogen group $\log_{10}$ reduction by filtration processes are summarized in Table 4-2. The classification of selected particulate matter by size compared against the effective range of filtration processes is shown in Figure 4-1.

The data shown in Figure 4.1 can be used as a general guide to evaluate the ability of the filtration process to achieve pathogen LRTs, with the caveat that variability in membrane design and integrity should be considered during the selection and evaluation of filtration processes. Pressure decay testing is the accepted method used to determine membrane $\log_{10}$ reduction.

Table 4-2: Observed Values for Pathogen Reduction Using Alternative Filtration Processes

Barrier	Example $\log_{10}$ Reduction Values[a]			Key Factors Impacting $\log_{10}$ Reduction Values
	Virus	Protozoa	Bacteria	
Slow sand filter	2 (2 – 3)	4 (3.9 – 7.1)	2 (0.6 – 5)	Sand effective size, filter bed depth
Dual media filter with coagulant	1 (0.5 – 3)	2 (1.5 – 2.5)	1 (0.25 – 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 (2.5 – >4)	0	Absolute pore size, hydraulic shock
Cartridge/bag filter (1-micron absolute)	0	4 (2.5 – >4)	0	Absolute pore size, hydraulic shock
Diatomaceous earth (DE)	1 (0.4 – 3)	4 (3.5 – 7.7)	2 (0.1 – 3.3)	DE grade
Microfilter	1 (0 – >2)	>6 (4 – >6)	6 (3.5 – >6)	Membrane age, pressure decay testing, integrity testing, integrity testing
Ultrafilter	>6 (4 – >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 EPHC (2008); U.S. EPA (2005); Harrington et al. (2001).

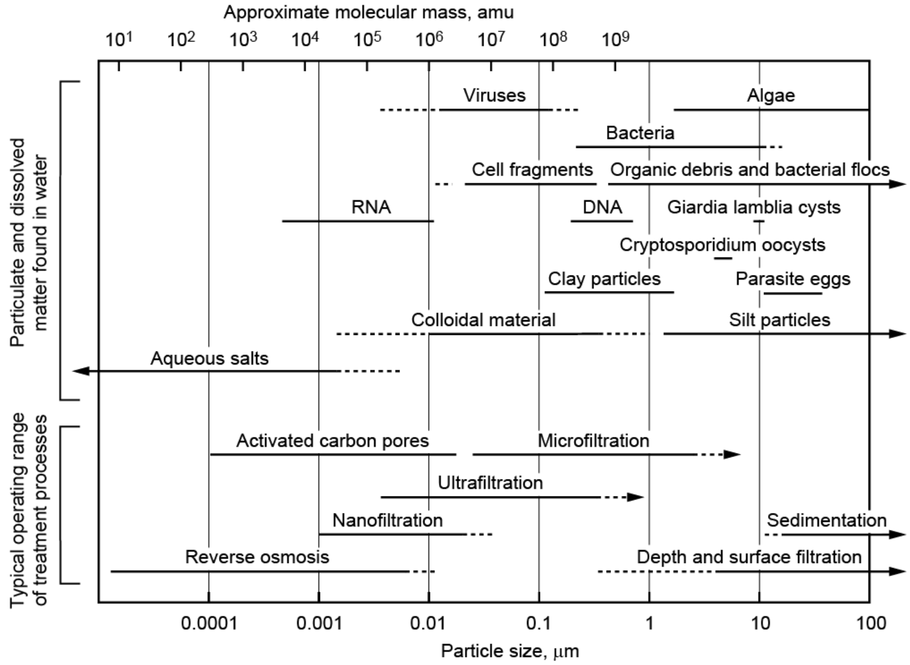

Figure 4-1: Size ranges of pathogens and selected particulate matter in water compared with operational ranges for common filtration processes (adapted from Tchobanoglous et al., 2014).
Note: "amu" stands for "atomic mass units" and "µm" stands for "micrometer."

4.4 Pathogen Reduction by Disinfection Processes

Processes for pathogen inactivation include disinfection by chlorine, peracetic acid, ozone, ultraviolet (UV) radiation, advanced oxidation, and pasteurization. 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).

In general, the efficacy of a chemical disinfectant agent is impacted by turbidity, organic carbon content, ionic strength, pH, temperature, and non-target reactants in water. Reactors for disinfection processes also need to be evaluated for hydraulic effects, impacts of appurtenances, and the operation of monitoring equipment. Each process will have specific considerations during testing and validation studies. For example, the operating conditions for UV systems must account for factors like the UV absorbance of water, lamp fouling and aging, measurement uncertainty of online sensors, UV dose distributions arising from velocity profiles through the reactor, failure of UV lamps or other critical system components, and inlet and outlet piping configurations of the UV reactor (U.S. EPA, 2006).

Literature reports and/or bench testing can be used to develop improved estimates of expected $\log_{10}$ reduction for a specific water and disinfectant combination. Alternative chemical disinfectants, such as bromine, iodine, and hydrogen peroxide are not well represented in the literature and must be evaluated through bench testing or other means if they are to be considered.

Relative values for the inactivation of pathogens for alternative disinfection processes in filtered water are given in Tables 4-3 through 4-5. These values serve as a guide to the relative effectiveness of different disinfection technologies and are not for a specific microorganism.

4.5 Considerations for Process Log_{10} Reduction Data

The LRVs presented in Sections 4.2 through 4.4 can be used for preliminary planning and evaluation. The topics discussed in this particular section include: 1) determining design LRVs for individual processes; 2) discussing the multiple barrier approach to process design; and 3) determining overall multiple barrier treatment train log_{10} reduction.

4.5.1 Determination of Design (Validated) Log_{10} Reduction Values

The pathogen removal performance of individual unit processes will depend on a number of factors, including the presence of interfering constituents, performance of preceding unit processes, variations in loading, and other process-specific considerations. Two basic alternatives are available for the selection of design LRVs: 1) use of literature values obtained from previous validation testing; and 2) *in situ* process challenge testing/sampling. The decision regarding which approach to use for design LRVs depends on the Management Category and preference of the system design engineer.

Table 4-3: Observed Values for Various Levels of the Inactivation of Enteric Virus in Filtered Secondary Effluent with Selected Disinfection Processes[a]

Disinfectant	Unit	Dose for Corresponding Log_{10} Reduction Value			
		1 Log_{10}	2 Log_{10}	3 Log_{10}	4 Log_{10}
Free chlorine	mg • min/L		1.5 – 1.8	2.2 – 2.6	3 – 3.5
Chloramine[b]	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

[a] Adapted in part from Tchobanoglous et al. (2014).

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

[c] Adapted from U.S. 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).

NA = Not applicable. mg•min/L = Milligram-minutes per liter. mJ/cm^2 = Millijoules per square centimeter.

Table 4-4: Observed Values for Various Levels of the Inactivation of Parasitic Protozoa in Filtered Secondary Effluent with Selected Disinfection Processes[a]

Disinfectant	Unit	Dose for Corresponding Log_{10} Reduction Value			
		1 Log_{10}	2 Log_{10}	3 Log_{10}	4 Log_{10}
Free chlorine	mg • min/L	2000 – 2600	NA	NA	NA
Chloramine[b]	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

[a] Adapted in part from Tchobanoglous et al. (2014).

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

[c] Adapted from U.S. 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).

NA = Not available. mg•min/L = Milligram-minutes per liter. mJ/cm^2 = Millijoules per square centimeter.

Table 4-5: Observed Values for Various Levels of the Inactivation of Enteric Bacteria in Filtered Secondary Effluent with Selected Disinfection Processes[a]

Disinfectant	Unit	Dose for Corresponding Log_{10} Reduction Value			
		1 Log_{10}	2 Log_{10}	3 Log_{10}	4 Log_{10}
Free chlorine	mg • min/L	0.4 – 0.6	0.8 – 1.2	1.2 – 1.8	1.6 – 2.4
Chloramine[b]	mg • min/L	50 – 70	95 – 150	140 – 220	200 – 300
Peracetic acid[c]	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	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] Adapted in part from Tchobanoglous et al. (2014).

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

[c] Linden et al. (2012).

[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).

mg•min/L = Milligram-minutes per liter. mJ/cm^2 = Millijoules per square centimeter.

Applications expected to have a low risk of exposure (e.g., Management Category 1 and sometimes Management Category 2) may not require rigorous test programs to obtain LRV data. For other applications, the appropriate time to conduct LRV studies will need to be specified in the commissioning plan, which is a component of a PAR (Chapter 8). In particular, biological processes may require a start-up period of several months to reach pseudo-steady state prior to determining LRVs. Systems that incorporate a high level of water recycling will require some time to reach steady state as constituent concentrations in the recycled water stabilize. For low-risk applications, it usually is sufficient to select process LRVs from literature references, such as the values presented in Tables 4-1 to 4-5.

Test data need to be obtained for processes that need to be better characterized using new processes/technologies, existing processes that have been modified, and new or existing technologies for unique water/wastewater flows. In cases where data collection is necessary, performance data should be collected with care and in such a way that the influent and effluent samples are correlated or paired. In some cases, correlating influent and effluent samples can be achieved by preparing a sufficiently large batch of challenge water to ensure that no dilution takes place during the effluent sample collection process. The correlated influent and effluent samples can be used to compute the LRVs for the process. The observed LRVs can then be used to determine the VLRV. In some cases, the VLRV can be taken as the lowest observed value in a dataset. As a result, the jurisdiction will need to specify the number of samples required (typically 4 to 10), depending on factors related to process implementation and the water-use scenario. An alternative technique is to use a probabilistic approach, as described below, to determine the nature of the distribution and VLRV.

The probabilistic approach for analyzing LRVs is based on collecting data to develop the cumulative probability density function (CPDF) for a given process and operational scheme. Data obtained from operations or process testing can be used to estimate and plot the CPDF as a cumulative probability plot (Khan and McDonald, 2010). In developing the cumulative probability plot, independent measured values are arranged from smallest to greatest, and a plotting position is assigned to each value (Crites and Tchobanoglous, 1998). The plotting position is defined as:

$$p_i = \frac{100(i - 0.5)}{n}$$

(Equation 4-1)

Where:

- p_i is the probability associated with the ith data point.
- i is the ith data point in a dataset.
- n is the number of data points.

The CPDF is used to determine the frequency of occurrence for a given value. For example, LRV_{05} represents the LRV for a given process that is exceeded 95% of the time (i.e., the lower fifth percentile). For critical processes used to control pathogens, the LRV_{05} value is used as the VLRV. It is recommended that enough samples are collected to characterize the distribution adequately. The measured values must be independent and representative of the underlying distribution. See Figure 4-2 for an example of $\log_{10}$ reduction data from an ozonation process. Notably, the variability in the performance of most water treatment processes results from various factors and the resulting distributions are typically lognormal.

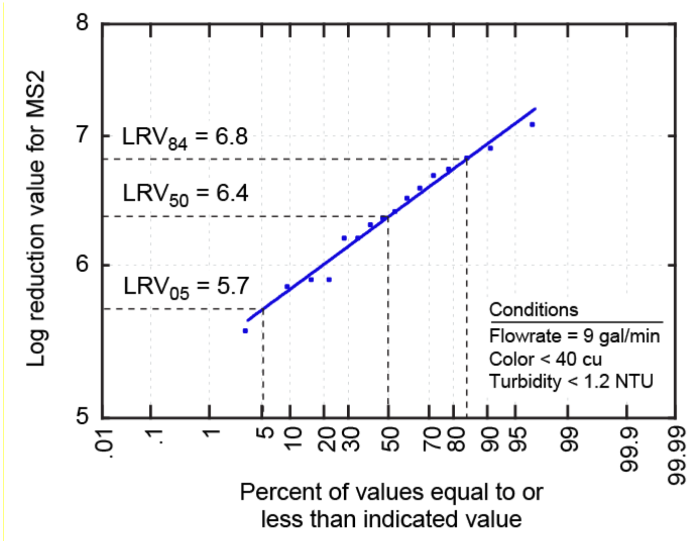

Figure 4-2: Example of a lognormal cumulative probability plot of validation data for $\log_{10}$ reduction of MS2 coliphage for the proposed ozonation process.

For the data shown in Figure 4-2, the $VLRV_{05}$ is 5.7. The lognormal cumulative probability curve can be described with two key parameters: the geometric mean LRV ($M_g = LRV_{50} = 6.4$) and geometric standard deviation ($s_g = LRV_{84}/LRV_{50} = 6.8/6.4 = 1.06$).

4.5.2 Multiple Barrier Design

Most non-potable water systems use a number of unit processes in series to accomplish treatment, known commonly as the "multiple barrier" approach. Multiple barriers are used to improve the reliability of a treatment approach through process redundancy, robustness, and resiliency.[6] When multiple treatment barriers are used to achieve the pathogen LRT, the contribution from each barrier is cumulative; therefore, a reduction in performance by one process is mitigated by other processes in the treatment train. An example multiple barrier treatment train, consisting of anaerobic treatment, aerobic treatment, sand filtration, ozonation, and chlorination, is shown in Figure 4-3.

In addition to these treatment barriers, operational and management barriers are used to ensure that systems are in place to respond to non-routine operation. Treatment barriers can be monitored using sensors and instrumentation for continuous process monitoring. An important ability is to take the treatment train offline automatically in the event of process malfunction.

[6] **Treatment reliability**: The ability of a treatment process or treatment train to consistently achieve the desired degree of treatment, based on its inherent redundancy, robustness, and resilience.

Redundancy: The use of multiple treatment barriers to attenuate the same type of constituent so that if one barrier fails, performs inadequately, or is taken offline for maintenance, the overall system still performs effectively and risk is reduced.

Resilience: The ability to adapt successfully or restore performance rapidly in the face of treatment failures.

Robustness: The use of a combination of treatment technologies to address a broad variety of constituents and changes in concentrations in source water.

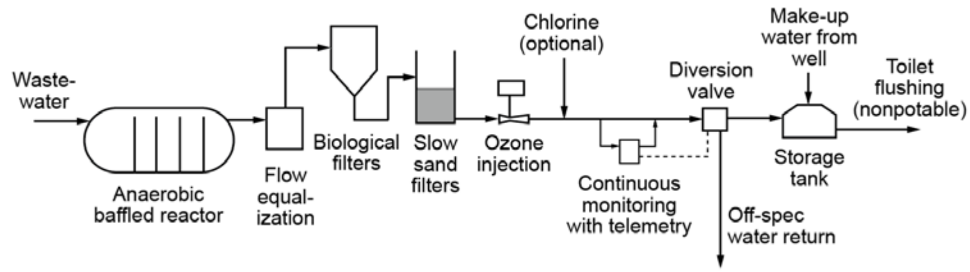

Figure 4-3: Example of a multiple barrier treatment train for a blackwater source used for toilet flushing.
Note: this image is duplicated in Figure 9-2 in Chapter 9.

4.5.3 Overall Treatment Train Log_{10} Reduction

If each barrier in a treatment train is assumed to be independent, the LRVs for each process in the treatment train can be added together to obtain the overall treatment train LRV. One approach for the overall LRV is to use a summation of the design LRVs from individual processes. An example of virus removal data obtained during *in situ* pilot testing is presented in Figure 4-4, and alternative treatment train LRVs are summarized in Table 4-6. The sum of the LRV_{50} for each barrier is a recommended approach for determining a treatment train LRV.

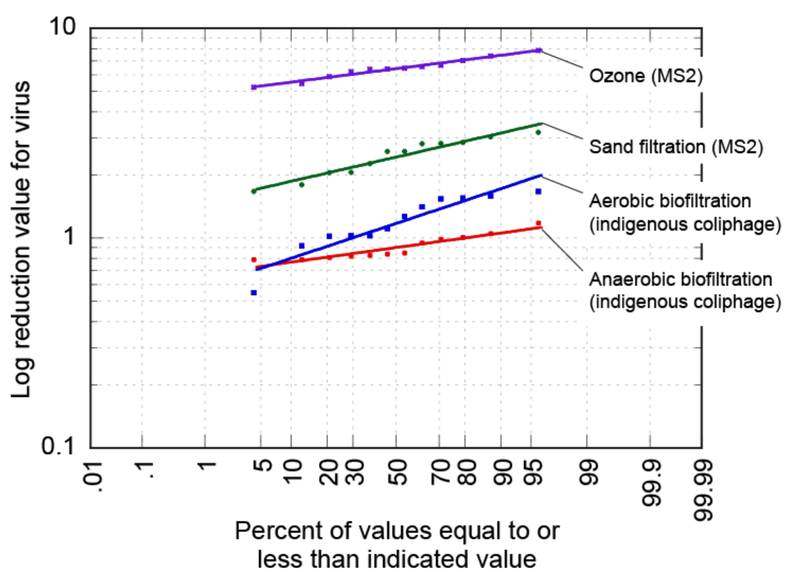

Figure 4-4: Measured virus removal data for the processes shown in Figure 4-3.
Note: “MS2” refers to MS2 coliphage.

As described above for the individual process LRV, a probabilistic approach can be used to determine the LRV for the overall treatment train. If it is assumed that each process operates independently and with performance as defined by the probability distribution, a Monte Carlo technique can be used to simulate the aggregate treatment train performance (Olivieri et al., 1999). See Appendix C for a description of this approach. For many DNW systems, the effort associated with developing and interpreting the analysis resulting from the Monte Carlo method will not be justified. In addition, data collection may be costly and infeasible for some applications; however, using the probabilistic approach to select the design LRT is beneficial because the distribution can be approximated with relatively few data points.

Table 4-6: Process Virus Log_{10} Reduction Values Obtained during Pilot Testing

Disinfectant		Log_{10} Reduction Value (LRV)				Geometric Standard Deviation
	Surrogate	Lowest Observed	LRV_{05}	LRV_{50}	LRV_{84}	
Anaerobic biofiltration	Indigenous coliphage	0.8	0.7	0.9	1.0	1.13
Aerobic biofiltration	Indigenous coliphage	0.6	0.7	1.2	1.6	1.35
Sand filtration	MS2 coliphage	1.7	1.7	2.4	3.0	1.23
Ozonation	MS2 coliphage	5.2	5.7	6.4	6.8	1.06
Treatment train total		8.3	8.8	10.9	12.4	

Table 4-7: Alternative Overall Treatment Train Log_{10} Reduction Values

Parameter	Value
Summation Method (n = 10)	
Lowest observed	8.3
LRV_{05}	8.9
LRT_{10}	9.3
LRT_{50}	10.9
Monte Carlo Method (n = 10,000)	
LRT_{05}	9.3
LRT_{10}	9.6
LRT_{50}	10.8

CHAPTER 5

Tiered Management Approach for Decentralized Non-Potable Water Systems

5.1 Overview

One of the most challenging aspects of DNW system infrastructure is ensuring these systems provide safe, affordable, and dependable service to customers. The traditional models that regulate the operation and ownership of potable water supply systems must be modified to adapt to the scale and complexity that are characteristic of DNW systems. In previous chapters, the Panel discussed appropriate water quality requirements and efficient means of monitoring and collecting data. In this chapter, the Panel discusses the means for implementing: 1) accountability of long-term system performance; and 2) checks and balances to ensure proper O&M.

All aspects of the business model must be considered, from the planning and design of systems through implementation and long-term management. The control and management mechanisms must fit the nature and risk of the service provided such that these systems are neither over-regulated and become too expensive nor under-regulated and allowed to malfunction without consequence to the owner and operator. There is no "one-size-fits-all" solution, but rather a menu of options that equally guide and protect a single homeowner who simply collects rainwater from her/his roof as a source of toilet flush water, as it does for a neighborhood-scale wastewater reuse system that serves 1,000 customers and supplies an array of non-potable water uses.

5.2 Background on the Responsible Management Entity

The term Responsible Management Entity (RME) was first used by the U.S. EPA in 1997 in response to growing recognition that decentralized wastewater systems would play a more significant role in addressing water quality in the United States than originally thought with the adoption of the Clean Water Act in 1972. A number of parallels exist between the DNW system approach proposed herein and earlier considerations for decentralized wastewater treatment and disposal systems. In particular, these systems typically are owned and managed by an individual property owner or private entity, rather than by a public utility. In addition, the design and operation of a decentralized system requires specific attention to the sensitivities of smaller flows and greater site-specific variability. The similarities between DNW systems and decentralized wastewater treatment and disposal systems are worth considering, modifying, and adapting as appropriate in creating a framework for DNW systems. Most important is the recognition that the decentralized asset model is viable only if appropriate accountability for performance is established.

RME emerged as a term used by the decentralized wastewater industry to describe an array of possible regulatory, oversight, and management structures that divide roles and responsibilities appropriately between the local regulator, owner, and operator of smaller systems. For this report, the Panel has applied the term RME to DNW systems, recognizing that DNW systems have many of the same characteristics and challenges as decentralized wastewater systems, but also have some significant differences. Similarities mostly stem from the small scale and complexity of treatment mechanisms, whereas differences are associated with: 1) the greater need for accurate and reliable performance from DNW systems; and 2) the greater potential economic and environmental benefits offered by the DNW system model.

The drivers for decentralized wastewater models are environmental or health-related problems, whereas the drivers for the DNW system model are the opportunities to improve the resilience of water supplies on a uniform basis and to save money (when justified by local water and wastewater costs). Both models have similar quality-of-life characteristics, but different economics.

Ownership and accountability are core issues of potable water supply and wastewater treatment. Historically, the focus of regulations logically targeted the higher-risk larger systems that affect more people and have significant negative impacts if they fail to perform as planned. Small systems also have been regulated (although more loosely), but often create concern for the regulatory community due to complexities that arise from their smaller scale, lower impact, and greater diversity.

Although the Safe Drinking Water Act primarily targeted larger regional or utility-scale potable water supply systems (with 15 service connections or 25 or more people served), it also provided for the well water supplies of individual customers through a blend of federal, state, and local regulations and controls that varied across jurisdictions. The Safe Drinking Water Act also acknowledged the impact of larger-scale onsite sewage systems by considering them Class V underground injection wells. As a result, there was clear recognition of the need to control decentralized water supply and decentralized wastewater disposal simultaneously to achieve adequate public health protection.

On the wastewater side, until the late 1990s, the Clean Water Act sought to eliminate wastewater pollution strictly through large-scale centralized systems owned and operated by governmental and non-governmental entities, often created for that specific purpose. The responsibility for small-scale decentralized wastewater systems fell to the individual property owner under the regulatory oversight of the local public health jurisdiction. Consequently, the local health agency tended to be responsible for both decentralized water supply systems and decentralized wastewater disposal systems.

Due to advances in science and technology (and the realization that building sewers and centralized wastewater treatment facilities in every community is economically unfeasible), it became clear to the water industry that small-scale decentralized wastewater systems eventually would provide long-term wastewater services for approximately 25% of the population and become a permanent part of wastewater infrastructure. New management models were needed to provide a higher level of oversight, control, and accountability of the performance of decentralized wastewater systems.

Thus began the era of defining and implementing the newly coined term Responsible Management Entity or RME. Simultaneously and (often) synergistically, discussions of decentralized wastewater systems and the overall concept of new and improved methods of water resource management now incorporate the use of DNW systems (Johnson Foundation, 2014). Various drivers originating from the green building industry – together with periodic droughts, floods, and climate change issues – continue to broaden and intensify the focus on this topic.

References that describe considerations for RME-based decentralized wastewater management systems can be found in a number of places and span nearly two decades (U.S. EPA, 2012; WERF, 2009; EPRI, 2010). These documents describe a progression of responsibilities starting with simple public education programs and expanding to an intensive, fully responsible utility ownership model.[7] This prior work and subsequent case studies have informed the discussion of best management practices for DNW systems.

5.3 Roles and Responsibilities

Years of study and experience invested in developing the decentralized wastewater RME concept provide an excellent framework and basis for defining RMEs for DNW systems. Some core characteristics transpose directly, while others require modification.

Defining the most appropriate RME model for each community will vary depending on the following:

- Existing local water regulatory structures.
- Specific physical characteristics of water assets.
- The owners of the water assets and their authorized powers.
- Resources available to the owners of water assets.
- Local stakeholder perspectives on risk management.

Some communities will prefer higher levels of direct governmental management and oversight of system performance for risk mitigation, while others will defer most performance risks to non-governmental entities and individual owners. In all cases, clarifying the roles and responsibilities for system performance is key in establishing the framework for system management. As shown in Figure 5-1, the key attributes of the roles and responsibilities of an RME factor into all aspects of all DNW systems.

There are many possible combinations of the roles and responsibilities illustrated in Figure 5-1, which vary according to the specific characteristics of each community and how each community desires to manage its DNW system. The community can choose to share in these risks or defer the risks to others. As discussed in Chapter 2, the risk of exposure varies according to the number of people exposed on a daily basis and to the likelihood of system malfunction, which increases with the complexity of the system and the level and nature of source water contamination.

Based upon these factors, the considerations for each Management Category (see management responsibilities in Table 2-1 of Chapter 2) include the following:

- **Management Category 1.** The building owner assumes all responsibility and is not required by the regulator to provide reports or collect data. The regulator only provides educational support. There may or may not be some form of system registration or licensing. This type of system has a low risk of exposure considering the customer base is small and the risk of malfunction is low. System components are simple and the level of pathogens contained in the source of supply is low.

[7] The WE&RF's Responsible Management Entity (RME) Guidance Fact Sheet, prepared in 2009, refers to four levels of RME intensity (Maintenance Contract, Operating Permits, RME Operation and Maintenance, and RME Ownership). In contrast, the U.S. Environmental Protection Agency's Case Studies document (U.S. EPA, 2012) refers to five levels, having inserted a more basic "Homeowner Awareness" step to illustrate when the local regulatory agency simply informs system owners of their responsibilities without taking any specific licensing or enforcement role.

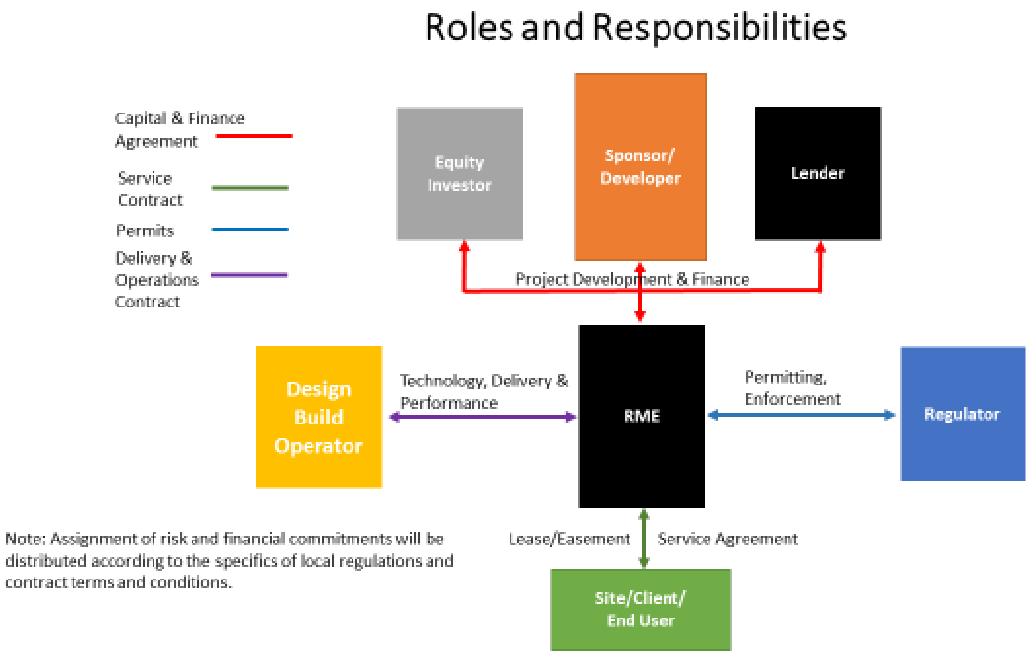

Figure 5-1: Key attributes of the roles and responsibilities of Responsible Management Entities.

- **Management Category 2.** The building owner retains responsibility for system performance, but due to a higher level of system complexity and more contaminated sources of supply or higher exposure from the end use, the equipment must be proven effective (i.e., certified) and an approved (i.e., registered) service agent must provide maintenance service. The risk of exposure remains small due to the small customer base, but the risk of malfunction increases with the complexity of the system. The building owner contracts directly with the service agent, but the regulator registers the service agents and ensures they are qualified, use appropriate equipment, and provide adequate services. In this case, the regulator may require licensure, data collection, and reporting.

- **Management Category 3.** The larger customer base and increased complexity of the system require a high level of management and responsibility similar to that of public utilities. The risk of exposure is now much higher due to the number of daily users and the possibility of broader public access to the system. Risk of malfunction also may be higher due to the complexities of the source of supply and the biological and physicochemical treatment mechanisms need to serve a larger customer base. The RME is a prequalified entity with proven capability and experience, and it must have financial security to ensure long-term performance. The regulator licenses the system, reviews periodic reports submitted by the RME, and holds the RME accountable for safe and dependable service. It is the responsibility of the RME to ensure the entire system (i.e., collection, treatment, storage, and distribution) is fully functional, properly maintained, and compliant with treatment requirements at all times. The RME must have the financial and human resource capabilities to handle all repair and replacement needs and must provide emergency response to address any operating problems. The RME also must provide customer service to address questions and complaints.

Because of the range of risks associated with specific system configurations, the regulatory authority should create appropriate registrations or permit requirements that account for differences among systems and establish reporting requirements accordingly. This effort, in turn, likely would parallel a commensurate range of RME qualifications. Consistent with the hierarchy concepts established in legacy RME programs for decentralized wastewater systems, it is logical to have a range of regulatory oversight controls from "least imposing" to "most demanding" and parallel RME qualifications that range from "simple self-regulating" to "fully accountable."

A number of considerations must be addressed at the outset regarding the best arrangements for RME structure and controls. Regardless of the specific RME configuration, the roles and responsibilities illustrated in Figure 5-1 must be fulfilled in all cases, even for the simplest individual building owner system where the owner wears all the RME hats at once. As systems become larger and more complex, the team associated with developing, financing, delivering, and operating the system will grow to include a number of entities. Yet, in all cases, it is critical that only one RME be fully accountable for performance and delivery.

It also is critical that the regulator establish clear and reasonable regulations. An effectively functioning RME invites the involvement of the regulator and is transparent with data sharing and information about system performance. The more consistency between regulators, the better, although different jurisdictions will have different dynamics because of local variabilities in existing regulations, resources available to regulators, and constraints and opportunities offered by owners of existing infrastructure.

Lastly, the customer must be engaged in using the system and must abide by a clear, fair set of service rules imposed by the RME. Because misuse of the system could be detrimental to performance, the RME must have the ability to impose appropriate service rules and the authority to respond appropriately to control customer behavior and eliminate misuse. Logically, the RME would need to use the full extent of the law to collect fees for services rendered, including shut-off provisions for failure to pay. Regulators should consider these factors in the requirements for DNW systems when the RME is not a municipal utility or entity. Some RME providers may have limited power within the law.

5.4 Performance Security

A properly developed RME–regulator–customer program provides strong measures to control performance and ensure the safe, affordable, and dependable service of the DNW system. Even with a solid program in place, the RME must remain financially secure and assume adequate financial liability to avoid situations in which DNW systems with performance problems are abandoned. The main concern of most regulators is that RMEs of systems with Management Categories of 1 or 2 will ignore performance requirements or RMEs of Management Category 3 systems will collapse or walk away from problems too difficult to resolve. This concern is greatest with RMEs of Management Category 3 systems that serve large numbers of people. The following considerations are instrumental in achieving the desired success of an RME:

- **Financial security.** The RME should post with the regulator a performance guarantee that approximates operational costs for a minimum of 1 year. The guarantee can be in the form of an approved bond or another secure financial arrangement. One year of operational costs represents a typical guarantee for the industry and is a reasonable amount of deterrent to ensure the RME remains vigilant with performance at all times.

- **Operating reserves.** The RME should prove to the regulator that adequate operating reserves are available to pay for repair and replacement costs, as well as capital expenses to protect the longevity of the system. As with any utility, quality performance requires adequately maintained assets.

- **Service territory.** The RME must be allowed to operate efficiently within a defined territory and should not be limited to operating a single stand-alone DNW system. Granting a limited number of franchises within a territory to an RME is one way to encourage it to become competitive and benefit from the opportunity to invest in and manage multiple systems.

- **Review and approval of RMEs.** The screening and approval of RMEs is an important aspect of allowing operations within a service territory. RMEs should be required to provide qualifications relating to performance history, experience with DNW systems, core skills and capabilities, and financial strengths. Regulators should review and approve an appropriate number of RMEs to provide services within their territories.

- **System redundancy.** Many urban DNW systems will benefit from parallel centralized potable water and sewer systems, so that the DNW system can be shut down for periods of time without any inconvenience to customers and little impact to the centralized systems, providing they are appropriately configured. A key strength of the DNW system model relates to the fact that problems typically occur only to singular systems at any given moment in time. The ability to shut down helps the regulator implement a strong quality performance program, while also helping the RME manage brief periods of equipment malfunction or perform routine maintenance. In areas where access to centralized services is available, it is possible to design an efficient system configuration that reduces costs and improves non-potable water demand. In areas where centralized services are not available, the DNW system must provide adequate back-up protections and equipment redundancy to allow uninterrupted service corresponding with potable water supply systems.

Regulators need to consider the above aspects of performance security and implement the best model for their communities. Solid performance protection with efficient controls will help keep costs down and improve customer satisfaction and system use. Another key to success is to ensure RMEs have adequate experience and expertise in water system management. Experience in managing potable water, wastewater, and stormwater systems increases the capability for successfully managing Management Category 2 and 3 DNW systems. Regulators will need to define the specific qualifications required for RMEs within their jurisdictions.

5.5 Monitoring and Reporting

Monitoring and reporting requirements will vary according to the level of risk exposure or Management Category of the RME. More detailed and specific system monitoring guidance is discussed in Chapter 6. Reporting is addressed in Chapter 8.

Using New York City's DNW system model as an example, RME Management Category 3 systems include automated monitoring, control, alarm, and data logging. The data are summarized, confirmed using monthly grab samples, and analyzed by an independent laboratory. Certification and reporting to the City is on an annual basis and requires the signature of a licensed professional engineer.

Each regulatory jurisdiction will need to determine the specific monitoring and reporting requirements commensurate with their other water quality programs.

5.6 Responsible Management Entity Structure and Asset Ownership Options

Several structures and ownership options for RMEs are available. To date, noteworthy examples include privately owned RMEs for DNW systems, as well as public ownership and nonprofit cooperatives. One factor that orients this model toward private ownership is the placement of assets within private buildings and on private property. Public ownership of DNW systems is less similar to other models of public asset ownership and less desirable to the public owner. Refer to Table 5-1 for a summary of key differences (including strengths and weaknesses) between the various ownership options.

Table 5-1: Responsible Management Entity Structure and Ownership Options

Entity	Role	Strength	Weakness
Municipality	Public finance; own; operate; contract for services; regulate.	Tax-free financing; access to federal funding; combines multiple public services for efficiency; backed by taxation security.	Political drivers create instability; municipal or county debt limitations; service area limitations restricted based on political boundaries; labor costs carry governmental requirements; entry to private property and buildings has liability and privacy considerations.
Quasi-Governmental, Special District, Authority, Public Nonprofit	Public finance; own; operate; contract for services; sub-regulate.	Tax-free revenue-based financing; access to federal funding; focused services; guaranteed by taxing authority.	Diversion from public objectives possible; inflexibility; labor costs carry governmental requirements.
Cooperative, Private Nonprofit (Association)	Public and private finance; own; operate; contract for services; sub-regulate.	Revenue-based financing separate from public debt structure; access to federal funding; independent of political drivers.	Diversion from public objectives is possible; financial security is not backed by taxation; higher cost of debt.
Private For Profit: Determination required for applicability of Public Utility Regulation to DNW Systems	Private finance; own; operate; contract for services; sub-regulate.	Revenue-based financing separate from public debt structure; labor and operating cost efficiency gains; risk shedding for governmental entities; services and costs controlled by local governments.	Higher-risk of financial failure if inadequate securities provided; change of ownership possible.
Public-Private Partnership (P3)	Combination private-public financing; own; operate; sub-regulate.	Combines the benefits of other forms of ownership; tax-free revenue-based financing; access to federal funding; gains in labor and operating cost efficiency.	Success requires secure and carefully crafted contracts; financial security of private entities; necessary and fair public contracting and rate setting methods.

5.6.1 Governmental Authority (Municipal/County)

A governmental entity or entities could own the DNW system assets as part of the municipal infrastructure, operating the systems as a separate utility under the municipal governing body or as a part of the public works department. This structure is the current form of ownership for much of the existing centralized wastewater and water systems. Municipal ownership offers advantages in regards to access to public financing, but is more complicated in regards to civil service employment regulations, procurement regulations, and the influence of local politics on system management. In addition, specific funding rules vary by jurisdiction and may complicate the financing of DNW system infrastructure. For example, California General Obligation Bonds require two-thirds voter approval, thereby making issuance more complicated, time-consuming, and less applicable to this model (California Debt and Investment Advisory Commission, 2008).

Backing from a municipality's taxing power is advantageous for financial security, as the ability to qualify for low-interest funding and special incentives often is offered only to municipalities. The availability of different bond instruments varies according to the specific charter of the public agency (i.e., city, county, authority, redevelopment agency, and other). General Obligation Bonds, Revenue Bonds, and other bonds have specific purposes and uses that require investigation for each municipality. Infrastructure that is financially self-sufficient and fully supported by customer rate charges is desirable. The taxing power of the municipality should only support the financing of, not act as a supplement for, the system operation. This approach is only achievable with robust accounting and cost-control mechanisms.

Under the municipal option, inter-local service agreements can provide services to multiple municipalities; however, such arrangements may raise concerns about appropriate cost allocation and fairness to the partner communities. Restricting the services of the RME to a single municipality can greatly limit the ability to build a customer base and grow the RME.

Municipal RME/ownership may be the best option from a low-cost perspective, but it is less beneficial from the standpoint of operating costs given higher government overhead. It is least beneficial when considering the burden of public risk. If the system experiences problems, the risk of recovery falls on the municipality, which can financially affect those not served by the DNW system.

The complications of entry to private buildings and repairs that involve damage to the building (e.g., holes in the wall or leaks) may make the option of public ownership unattractive to municipal leaders and building owners. Creating a separate public utility for DNW systems, or combining it with existing public works services, may not be possible or popular.

5.6.2 Quasi-Governmental Authority, Special District, Public Nonprofit

The formation of a wastewater or combined water and wastewater authority provides a quasi-governmental management alternative. In general, such an alternative qualifies for all financial benefits offered by municipal ownership and carries many of the same procurement and management characteristics. The participating municipal governments, as appropriate, may appoint the governing body of an authority, which then secures independent financing with loans and bonds backed by the general obligation of the taxing power of the municipality. Under this alternative, the revenue from ratepayers must finance the assets fully, and debt generally falls outside municipal spending caps. This approach has the advantage of being independent from the political climate of the municipality, but could present difficulties if the authority develops ambitions differing from those of the governing bodies. The operating charter of the authority is defined in the initial formation, and can be difficult to change once bonds and loans are secured. The approach is not a flexible asset management mechanism, unless clearly defined as such initially.

In general, quasi-governmental entities follow the same civil service labor and operating characteristics of governmental entities, thus bearing similar cost characteristics. The ability to create service territories that cross municipal boundaries is an advantage, but requires the participating entities to cooperate closely in defining and meeting all competing goals and objectives. From the risk allocation perspective, this form of ownership provides one layer of protection to the residents that are not utility customers. If an outright failure to perform occurs, the financial obligation ultimately rests with the residents of the municipality or municipalities that formed and backed the authority.

Similar complications associated with entry to private property would apply to this quasi-governmental model as they do for the governmental ownership model.

5.6.3 Private Nonprofit, Cooperative, or Association

Users of the sewer system can form a private nonprofit entity, such as a cooperative or association, as one alternative; however, the use of private non-profit ownership options requires investigating the specific legal formation, operation, and governance requirements of each state. Homeowner associations (HOAs) are an example of a non-profit mutual benefit corporation supported by association fees paid by property owners for operation and maintenance (O&M) of the facilities. The HOA model is applicable nationwide, but with variations in applicability based on specific state regulations. It is a widespread and popular management approach for shared common assets. For example, 41,000 HOAs in California house approximately 25% of the state's population (Center for California Homeowner Association Law, 2016). The HOA is the most common form of asset management for residential developments, which may already include water and wastewater assets in addition to more commonly shared assets, such as parks, roads, community centers, and others.

Cooperatives are common and successful in the area of power supply utilities, though not commonly used for water and wastewater assets (although, in general, the legal provisions exist). The association form of ownership also can be a special purpose entity focused only on managing wastewater/water assets and, therefore, resembles a cooperative with regards to its service functions, if structured accordingly. A cooperative or association form of ownership separates the municipality from the financial responsibility of the facility's operation and management, but these forms of ownership are less viable with smaller customer bases that might lack the ability to provide adequate management and financial discipline.

Associations often have difficulty managing complex assets effectively and can experience financial problems if funding and maintenance are not adequate. HOAs may not have technically capable management or continuity of qualified board members, which further complicates this option. Ultimately, if an association falls into financial difficulty, then the municipality is the next logical entity to provide assistance. Although there is no legal liability, practical responsibility can implicate the municipality, should problems arise.

One appropriate means to overcome much of the performance risk is through a long-term contract with a larger, specialized private entity that can absorb all O&M responsibility and provide the required technical, managerial, and financial capabilities. Of course, the financial security provided by the private entity is then the next category of protection. It is important to ensure that financial security is adequate.

5.6.4 Private For-Profit Company

A private corporation is the most independent form of RME ownership wherein the municipality does not have any financial or physical obligations for managing the asset. Depending on the particular regulations of private utilities within each state, a private for-profit company may serve as an RME without financial regulation or may be required to register with the public utilities commission as a private utility. Typically, the for-profit private utility may be financed by private equity and a combination of private and public debt issued through State bonds or Federal subsidies.

The most significant risk with the private for-profit model is the long-term financial viability of the utility. It is for this reason that financial security in the form of performance bonds is needed to ensure adequate backing of the entity on a continuous basis. It is common to require financial reserves be available to ensure that system repair, replacement, and upgrades can be funded when needed. Because the utility must earn adequate income to fund its financial reserves, fair and thorough customer service contracts that ensure the utility maintains and services the installed DNW system are an important component for long-term success.

5.6.5 Public-Private Partnership

The Public-Private Partnership (or “P3”) arrangement is a more recent means of monetizing asset value without transferring ownership. A P3 transfers the risk of performance to a private partner while a public entity provides financing. Under this alternative, the governmental entities retain ownership and transfer operation and performance obligations to a private entity under a long-term contract, generally 20 years or longer.

This model is common in the renewable energy sector where new facilities are required, and increasingly considered, for water and wastewater assets. As with the private asset ownership model, the risk of performance in this case can shift entirely to the private entity, but only is as good as the financial security provided by that entity, should it falter. This option is favorable because it allows the use of private equity, greatly limits public risk, and can be tailored to many different options that include transferring assets to the public entity once the assets are fully proven after years of performance (referred to as “Design-Build-Operate-Transfer”). Funding opportunities for P3 arrangements encompass many traditional options associated with municipal bonds, State Revolving Funds, and private sources of funding.

CHAPTER 6

Process Performance Evaluation and Monitoring

Traditionally, water and wastewater systems have been monitored using fecal indicator organisms (FIOs). The presence or concentration of FIOs in samples of water or wastewater is considered indicative of other waterborne pathogens. FIOs have been useful because they are expected to be present in water contaminated with fecal waste. The use of FIOs for a DNW system, however, has limitations, including:

- FIOs may not be present in potential source water for a non-potable system.
- FIOs are not necessarily representative of all pathogen groups.
- Grab samples analyzed for FIOs cannot be used for continuous monitoring.
- FIOs are more difficult to measure consistently than other surrogate parameters.

Procedures for Evaluating and Monitoring Process Performance, as Presented in Chapter 6

- Determining LRVs for pathogens using surrogates by validation testing.
- *In situ* confirmation of LRVs by field verification.
- Continuous water quality monitoring using instrumentation to verify that pathogen removal targets are met rather than a conventional monitoring system using grab samples for FIOs.

6.1 Overview of Monitoring Systems

The monitoring approach proposed within this framework is substantially different from approaches currently used for DNW systems, which often require periodic sampling of FIOs and other water quality parameters. However, the basis for the proposed approach reflects widely accepted monitoring practices for potable water supply. Water quality monitoring and control systems are used commonly in potable reuse (both indirect and direct) and drinking water practice to assess the operation, performance, and status of a given component or process.

The use of monitoring technology in the practice of DNW system engineering is an extension of the approach accepted in existing and evolving water quality practice. For example, critical control points (i.e., specific processes that have a direct impact on water quality with respect to public health) are among the accepted approaches for monitoring disinfection systems in conventional potable water practice. In centralized non-potable reuse, adequate disinfection is determined commonly by maintaining acceptable filtered water turbidity and sufficient chlorine residual. In California, for example, Title 22 Recycling Criteria requires turbidity less than 2 Nephelometric Turbidity Units (NTU) after granular media filtration followed by chlorination with a median CT value of 450 mg•min/L. Similarly, a fundamental purpose of DNW system performance monitoring is to ensure that treatment barriers are designed to meet the specified LRT and operate as intended.

In this report, the Panel refers to pathogen control points (PCPs) as treatment barriers designed specifically to reduce pathogens of significance to public health. The PCP for a DNW system should include: 1) a continuous monitoring component; and 2) an automated or manual control element that allows for adjustment of process log_{10} reduction. An inherent assumption when using this monitoring approach is that a facility is in compliance if it operates in conformance with an approved O&M plan (included in the Project Application Report described in Chapter 8).

6.1.1 Types of Monitoring

Although many possible configurations are available for DNW systems, the three primary forms of monitoring include validation testing, field verification, and continuous verification monitoring.

PRIMARY FORMS OF MONITORING FOR DNW SYSTEMS

- **Validation testing.** A treatment technology process evaluation study conducted using challenge testing with target or surrogate pathogens over a defined range of operating conditions, usually conducted at a test facility or *in situ.*
- **Field verification**. Performance confirmation study, using biological and/or chemical surrogates, typically conducted during commissioning (if required) and repeated later (if needed). In some cases, indigenous organisms can be used for process verification. The need for, duration, and extent of the field verification procedure will depend on the characteristics and Management Category of the DNW system.
- **Continuous verification monitoring**. Ongoing verification of system performance using sensors for the continuous observation of selected parameters, including surrogate parameters correlated with pathogen LRT requirements.

A monitoring plan for a DNW system may include one or more of these three forms of monitoring. The Panel discusses each strategy in the following sections. See Figure 6-1 for a flow chart of process evaluation.

6.1.2 Monitoring Based on Management Category

As discussed in Chapter 2, monitoring system development will depend on the level of risk involved in a particular application. For low-risk scenarios consistent with Management Category 1 (e.g., landscape irrigation using roof runoff), monitoring systems are not required. For scenarios fitting within Management Category 2, simple monitoring systems are adequate and the PCP may be limited to one or more surrogate parameters correlated with performance. For Management Category 3 systems in which the risk is elevated, monitoring plans must include the multiple barrier approach, with monitoring at each PCP to detect potential problems throughout the treatment process (Tchobanoglous et al., 2015). For example, the reuse of blackwater for toilet flushing and clothes washing in apartments will require a higher level of monitoring to ensure the system meets LRT_{95} specifications. Example monitoring strategies are presented in Table 6-1 according to the different Management Categories identified in Chapter 2.

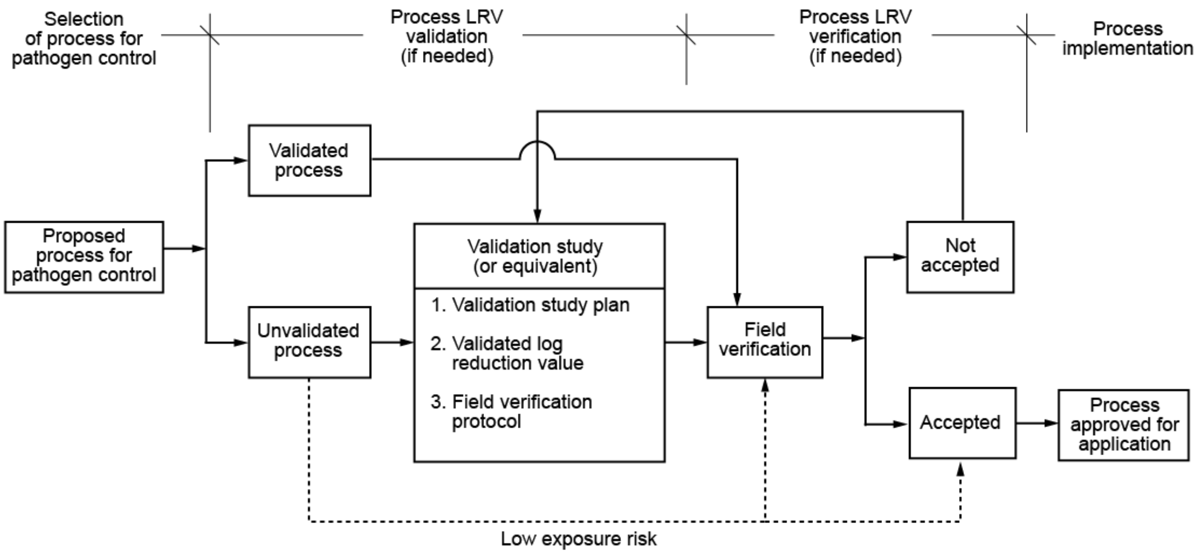

Figure 6.1: Flow chart for the evaluation of unit processes.

Table 6-1: Recommended Implementation of Monitoring Based on Relevant Risk Management Category (as defined in Chapter 2)

Management Category[a]	Monitoring Phase		
	Validation Testing	**Field Verification**	**Continuous Log_{10} Reduction Value Monitoring**
1	Not required, although various processes are acceptable.	Not required.	Not required.
2	Recommended for new/unknown processes. Known process may be approved based on results of previous testing with similar source waters.	A challenge test, performed at essential pathogen control points (PCPs), is recommended.	Required at PCPs with telemetry systems?. Monitoring at other points for process control is optional.
3	Processes used for pathogen control should have a documented validation test report or be subject to an *in situ* validation study.	Field verification of log_{10} reduction values at PCPs is required during the commissioning period or after significant process/loading changes.	Required at PCPs and process control points. A telemetry system with real-time alarm/data transfer to RME should be required. Automated control recommended.

[a] See Chapter 2 for detailed definitions of Management Categories.

6.2 Validation Testing

Performance validation testing is an independent evaluation to determine the VLRV that a given treatment process can be expected to achieve for the appropriate reference pathogens. Validation testing can be conducted at a suitable test facility or *in situ* during process commissioning. Validated LRV test results for unit processes designed as pathogen control barriers are required for Management Category 3 systems and recommended for Management Category 2 if the process is not well characterized. Well-characterized legacy systems may be considered to have the equivalent of validation testing, with LRVs confirmed through field verification testing (see Chapter 6.3).

SITUATIONS CONSIDERED FOR VALIDATION TESTING

- Applications deemed to have elevated risk (e.g., Management Category 3).
- Lack of relevant previous third-party test data from similar projects.
- New or untested treatment technologies (e.g., membrane elements).
- New or alternative process configurations.
- Source water with substantially different chemical characteristics than existing validation data (e.g., ionic strength).

If an application-specific validation study is conducted, the test plan should be reviewed and approved by the relevant regulatory agency in advance of the study, and implemented in association with a third-party testing consultant. See Table 6-2 for a summary of elements of technology validation studies. Selecting surrogates for validation monitoring should be based on the reference pathogen groups discussed in Chapter 3. See Table 6-3 for a summary of common surrogates used for validation monitoring of virus, bacterial, and protozoan removal. For accurate determination, it may be necessary to spike a high concentration of the challenge test surrogate prior to the process to be tested. High concentrations are used so that non-detect measurements are less likely and the maximum capacity of a treatment system can be determined. Refer to State of Victoria (2013) and NWRI (2012) for guidance on validation testing.

Notably, mono-dispersed organisms – as used in challenge tests – may not be representative of pathogenic microorganisms embedded in particulate matter (Asano et al., 2007; Sobsey, 1989). To reduce the uncertainty associated with determining VLRVs, an appropriate filtration system should precede disinfection processes such that free swimming or mono-dispersed microorganisms are present in the flow. If filtration is not used, it will be important to consider and account for the penetration of the disinfectant agent into particles through the application of a safety factor or specification of a maximum process LRV. Evaluate each system for the most appropriate challenge test procedure. While most validation studies use microbial surrogates, upcoming developments in the field of genomics and sensors could make conventional challenge testing and verification testing obsolete.

Table 6-2: Summary of Elements Involved in Technology Validation Studies[a]

Element	Description
Considerations in the Validation Study	
Pathogen removal mechanisms	Define the characteristics of a unit process used for pathogen reduction such that appropriate surrogates, interferences, and monitoring parameters can be identified.
Surrogates for challenge testing	Identify surrogates that: 1) are representative of the actual pathogens expected to be present; and 2) have removal mechanisms that are similar to that of the actual pathogens.
Factors that impact performance	Identify parameters that affect pathogen reduction for a given process and characterize them for monitoring in developing the validation study. Correlate these factors with performance during the study and define the scope of application for the process.
Surrogates for continuous monitoring	Continuous process verification requires that suitable surrogate parameters are available for detection using instrumentation. Define the relationship between the surrogate parameter and the level of removal for the reference pathogen group such that the operational boundaries can be specified.
Planning for the Validation Study	
Validation methodology and test plan	Use the test methodology to define the details of the challenge test, surrogates to be used, parameters to be monitored, sampling program, and quality control measures. Validation testing and related studies may include hydraulic analysis of reactors used for contact time, *in situ* testing of biological processes, and bench/pilot studies.
Data collection and analysis plan	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 study should include qualified personnel, appropriate analytical techniques, adequate documentation, calibrated equipment, and peer review.
Products of the Validation Study	
Operational monitoring and control strategy	The validation study should result in a viable approach to continuous monitoring of process-specific $\log_{10}$ reduction values. The monitoring approach should define the critical limits for surrogate parameters at each pathogen control point.
Process $\log_{10}$ reduction values	Processes should be assigned a validated $\log_{10}$ reduction value, typically the lower fifth percentile, for each reference pathogen group that is applicable when the process is operating as defined in the monitoring and control strategy. In some cases, the $\log_{10}$ reduction value may be limited by the monitoring technique.
Field verification protocol	While the validation study provides general guidance on applicability of a process for control of pathogens, some circumstances could require *in situ* acceptance testing, or field verification. Examples where field verification may be used include process changes, source water changes, and process interruptions. A simplified field verification plan should be included as an element of the validation study.

[a] Adapted from AWRCE (2009).

Table 6-3: Examples of Surrogates Used for Process Validation and Verification Studies

Surrogate	Description	Considerations
Surrogates for Enteric Viruses		
MS-2 coliphage	MS-2 (ATCC 15597-BI) uses host *E. coli* (ATCC# 15597). FRNA type coliphage used to achieve high seed virus concentrations	Size is 25 nanometer (nm) and isoelectric point at pH 3.9
PRD-1	PRD-1 uses host *Salmonella typhimurium* (ATCC 19585)	Size is 66 nm, contains internal lipid layer
Phi X 174 coliphage	Phi X 174 (ATCC 13706-B1) uses host ATCC 13706	Size is 27 nm and isoelectric point at pH 6.6
Fr coliphage	Fr coliphage (ATCC 15767-B1) uses host ATCC 19853	Size is 19 nm and isoelectric point at pH 8.9
B. pumilus	Spores of *Bacillus pumilus* (ATCC 27142)	Can be used as surrogate for Adenovirus due to resistance to inactivation by radiation (Boczek et al., 2016)
Surrogates for Enteric Bacteria		
E. coli	*Escherichia coli* is the default surrogate for fecal bacteria	*E. coli* is the principal member of the fecal coliform group. Fecal coliform are taken to be the subset of total coliform that are exclusively of fecal origin.
B. diminuta	*Brevundimonas diminuta* (ATCC 19146) has a small size (0.3 to 0.5 micron) and is easy to culture on nutrient agar	The small size of *B. diminuta* makes it useful for evaluating the integrity of membrane filters.
R. terrigena	*Raoultella terrigena* (ATCC 33257/33628)	Surrogate fecal indicator organism with size range of 2 to 4 micron
Surrogates for Pathogenic Protozoa		
B. subtilis	Microorganism that can form spores that are resistant to inactivation by chlorine	The spores of *Bacillus subtilis* can be used for integrity testing of processes that require a resistant organism.
PSL beads	Monodispersed polystyrene latex (PSL) beads are used to evaluate particle size exclusion during filtration challenge testing. Uniform PSL beads are available in sizes ranging from 0.0202 to >10 micron.	Analytical method for the enumeration of PSL beads is more complex and labor-intensive than other methods; however, sub-micron particle enumeration systems have been developed.

6.3 Field Verification

The purpose of field verification at PCPs is to check that the unit process is achieving LRTs and that operational monitoring and control systems are functional. Whereas validation testing requires evaluation over a range of relevant flow rates and conditions, field verification is used to show performance at one or more selected operating points. Typically, field verification occurs during commissioning, which encompasses all activities related to bringing a system into service. The commissioning plan, submitted as a component of a PAR (Chapter 8), is a detailed account of all activities associated with initial process operation through the completion of field verification studies. Field verification studies are conducted after process steady-state has been achieved, which could require several weeks for biological processes. The field verification of LRVs usually consists of a challenge test with an appropriate surrogate. Indicators for steady-state operation will be defined in the commissioning plan. New systems, systems that have been non-operational for a period of time, and systems with major changes in process configuration should be placed in service in accordance with a commissioning plan. Where required, the field verification test can take place during commissioning, after the system reaches a predetermined milestone in operation, or as a routine check. The commissioning period ends and regular operations begin after the Commissioning Report (see Chapter 8) is accepted, which includes results from the verification studies and other elements defined in the commissioning plan.

6.3.1 Application of Field Verification

In general, field verification studies take place during system commissioning. In some cases, however, field verification testing will occur after the DNW system has been placed into service. Examples of when field verification may be required after commissioning include:

- Correlating performance data with surrogate parameters for processes that have not been characterized adequately.
- After the stabilization of biological processes, with seasonal changes where applicable, and with alternate water supply blend ratios.
- When recycled water exceeds 50% of the flow, and it is expected that accumulation of constituents not removed in recycled water via installed unit processes may affect one or more unit processes.
- When a significant change in process configuration or equipment could affect performance.

Field verification of a treatment barrier consists of a challenge test using biological or non-biological constituents inoculated at high concentrations into the feed of the process under evaluation. Corresponding influent and effluent samples are collected for enumeration of the challenge test constituent to determine the $\log_{10}$ reduction achieved. In multiple barrier systems, where multiple control points are used, each barrier should be evaluated independently or as defined in the PAR.

Verification that LRTs are being achieved could be more complex when variability is high in the influent water source or when multiple water sources are blended together in various ratios that may result in changes in water chemistry that could affect the performance of a particular process. The commissioning plan should describe the process for accounting for variability in the water system during field verification.

6.3.2 Surrogates for Field Verification

In some cases, indigenous organisms can be used for determining $\log_{10}$ reduction performance. But it is not expected that there will always be sufficient surrogate organisms present in a non-potable source water suitable for conducting an adequate challenge test. Therefore, seeding with microbial constituents that are representative of relevant pathogens identified from the microbial risk assessment and that can be enumerated allows for the quantification of microbial $\log_{10}$ reduction. Future research could identify other endogenous markers that could be used for verification studies (see Chapter 10). See Table 6-3 for examples of surrogates used for field verification testing. Surrogates of microbial pathogens are used to assess the performance and operation of treatment barriers, such as filtration and disinfection systems. For example, challenge tests commonly are conducted using laboratory-grown MS2 coliphage to simulate the removal of the enteric virus reference pathogen (e.g., Adelman et al., 2016).

6.4 Continuous Process Monitoring

Continuous monitoring systems are used to determine if a treatment system is operating within the design specifications and if all systems are functional. Continuous LRV verification, used specifically for PCP monitoring, is described in Section 6.5. Continuous process monitoring involves the use of instrumentation systems for collecting process data at high frequency. In some cases, a specific target value for a monitored parameter may not exist. Instead, criteria to detect process malfunctions may be based on a specified percentage change over a given time period. For example, a greater than 5% change in turbidity over a one-hour period may indicate performance issues with a membrane filtration unit. To define the trend in a given criterion, historical data first must be collected to understand typical variability in a given parameter for a specified unit process. A final monitoring plan that includes criteria for defining out-of-specification performance of unit processes should be delivered with the Commissioning Report (Chapter 8).

Continuous monitoring data can be supplemented with manual observations by the RME to track activities related to process O&M procedures, such as calibrating sensors and online monitoring equipment; cleaning and replacing filters, membranes, and UV lamps; and confirming functionality of online telemetry and alarm systems. Refer to Table 6-4 for examples of parameters used for continuous monitoring. Notably, specific parameters will depend on the design of the DNW system.

In general, all systems will have some degree of monitoring during routine operation, either by manual observation or using instrumentation. In addition to operational monitoring data, trend data can be collected to identify potential problems before they occur. In some cases, continuous monitoring systems can be configured to contact the RME for service before process malfunction occurs. For example, in remote areas or for instances where O&M activities need to be minimized, water systems can be equipped with enhanced monitoring systems for the advanced detection of potential process failures.

6.5 Continuous Verification of the Log_{10} Reduction Value

In municipal-scale non-potable water systems, it is common practice to verify the safety of water by daily or weekly measurement of fecal indicators, such as thermo-tolerant coliform; however, Smeets et al. (2010) demonstrated that monitoring a single process required to achieve 6-$\log_{10}$ reduction, at a high level of confidence (95%), would require sampling every 10 seconds indefinitely. Consequently, monitoring strategies based on manual sampling for pathogens or FIO surrogates cannot detect process malfunctions reliably or with the needed frequency to ensure the delivery of safe water at all times. It is clear that continuous or higher frequency monitoring techniques are required for evaluating the performance of treatment and disinfection processes with high $\log_{10}$ reduction requirements.

Table 6-4: Examples of Parameters Used for Continuous Monitoring[a]

Unit Process	Example Monitoring Parameters
Influent/raw water	Flow rate into the water system; pH, temperature, conductivity, and other parameters in raw water.
Preliminary/primary treatment	Status of any inline filtration devices; status of online or offline equalization processes.
Physical/chemical treatment	Levels in chemical feed tanks; chemical injection flow rates and chemistry monitoring systems.
Biological treatment	Flow rate; residence time in treatment unit; pH, temperature, conductivity, and other parameters in reactor; biomass concentrations and wastage rates from reactor; process-specific parameters.
Membrane bioreactor	Membrane integrity; membrane flux; transmembrane pressure; permeate water quality; process pH, mixed liquor suspended solids, hydraulic retention time, solids retention time, food-to-microorganism ratio, dissolved oxygen, and temperature; flow rate.
Activated carbon/ion exchange contactors	Effluent constituents; flow rate through contactor; total bed volumes processed; pressure differential across contactor; bed regeneration/cleaning/backwashing cycles.
Slow sand, bag, cartridge,	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.
Media filtration	Filtration rate; filter run time; backwash rate; headloss; coagulant type, dose, and blending system; temperature, pH, alkalinity, and particle size analysis.
Membrane filtration (MF, UF, NF, RO)	Membrane integrity; membrane flux; transmembrane pressure; permeate water quality; process turbidity; electrical conductivity; total organic carbon and particle analysis; pH, mixed liquor suspended solids, hydraulic retention time, solids retention time, food-to-microorganism ratio, dissolved oxygen, and temperature; flow rate.
Ozone	Ozone residual; oxidation-reduction potential (ORP); color; ultraviolet light absorbance (UVA); turbidity/particle size distribution in flow entering the contact tank; oxygen generator output oxygen concentration and flow rate; inlet and outlet pressure at venturi, vacuum at venturi; residual ozone/color/ORP following contact tank; power consumption by oxygen concentrator and ozone generator; flow rate through venturi injector.
Advanced oxidation	Electrical conductivity; total organic carbon; ORP; color; UVA; turbidity/particle size distribution in flow entering reactor; process flow rate.
UV disinfection	UV intensity/applied dose; ORP; color; UVA; turbidity/particle size distribution in flow entering UV contactor; UV absorbance/transmissivity of flow entering UV contactor; applied UV dose/UV intensity; flow rate through UV contactor; lamp age and/or lamp output.
Free or total chlorine	Chlorine residual (free or chloramine); ORP; 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.
Sensors	Power consumption; sensors used to collect continuous data must be calibrated on a regular basis, checked against a reference standard, and serviced for replacement of electrodes, reagents, and other parts that wear out.
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; water quality for product water; check of corrosion control post-processing systems.

[a] Adapted from Tchobanoglous et al. (2015).

Continuous LRV verification is a subset of continuous process monitoring specific to determining if a given PCP meets the LRT goals as defined by microbial risk assessment (see Chapter 3) on an ongoing basis during routine operation. Continuous LRV verification is accomplished using monitoring data from inline sensors that detect a surrogate parameter, which correlates directly with a given process LRV, at a high sampling frequency. Data acquisition systems are used to collect and log process monitoring data in a local and/or online database at the frequency required to determine process compliance. DNW systems identified as Management Category 2 and 3 should undergo continuous process verification due to the elevated risk of exposure.

6.5.1 Surrogates for Continuous Pathogen Monitoring

For continuous LRV verification of process performance, it is common to use non-biological surrogates monitored with instrumentation. The basis for the correlation between sensor output and process LRV usually is defined during validation testing; however, a preliminary LRV relationship also can be established using data collected *in situ* during routine operation with existing systems or with pilot studies using similar source waters. The surrogates described in Section 6.2 are used for validation testing because their use is limited to manual sampling and laboratory analysis. The technology available today does not allow for the continuous direct detection of pathogens or FIO. See Table 6-5 for a summary of surrogate parameters commonly used to verify LRVs. In addition, processes that require contact time for reactions to take place (e.g., a chlorine contact tank) may need to be monitored for flow rate so that the product of concentration (C) and residence time (T) can be determined.

6.5.2 Monitoring at Pathogen Control Points

A PCP is a designated treatment barrier that uses a continuous monitoring system for detecting a surrogate parameter that correlates directly with LRVs for one or more reference pathogen groups. The PCP also should incorporate control features that allow for automatic or manual adjustment of the process LRV. For example, an ozonation system could use the oxidation-reduction potential as a surrogate parameter for virus $\log_{10}$ reduction. If the oxidation-reduction potential of the ozonated water drops below a specified level, the ozone output could increase automatically to compensate for higher ozone demand; alternately, the treatment train could be taken offline until the RME is able to diagnose and correct the malfunction and place the system back into service.

As discussed in Chapter 4, using the multiple-barrier approach to design a DNW system can improve overall process reliability, as the malfunction of any one process will have less impact on water quality than the malfunction of the entire process. Accordingly, it is necessary to monitor each barrier independently in a multiple-barrier treatment configuration using the PCP approach such that the cumulative LRV can be determined. Each PCP may include continuous monitoring of several parameters, analyses of trend data, alert levels related to process set points, and critical limits that should not be exceeded. Due to the variability of DNW system source waters and unit process configurations, it is not possible to generalize accurately the recommended targets for surrogate parameters that indicate a malfunction in process performance. Instead, target values should be recommended on a case-by-case basis through validation and/or field verification testing, as well as documented in the PAR (see Chapter 8).

Table 6-5: Surrogate Parameters Used for Continuous Process Verification Monitoring at Pathogen Control Points[a]

Surrogate	Applicable Processes	Considerations	Description
Ultraviolet (UV) light absorbance /UV light transmittance (e.g., UVA_{254})	UV disinfection Ozonation Advanced oxidation	Water with high absorbance/low transmittance is difficult to treat using UV; alternately, absorbance can be correlated with degree of treatment and disinfection where chemical oxidants are used.	The amount of energy at a particular wavelength taken up (absorbed) or passed (transmitted) in a liquid sample.
Chlorine residual	Chlorination	The product of residual concentration of chloramine or free chlorine and total contact time correlates with the reduction of some pathogens or biological surrogates.	The concentration of free or combined chlorine in water following a given reaction period.
Color	Ozonation Chlorination	In water with background color, correlations between the removal of color through chemical oxidation and the reduction of viruses have been observed.	A correlation with visible color of water determined by absorbance at wavelengths ranging from 420 to 460 nanometers.
Electrical conductivity	Reverse osmosis Nanofiltration	Removal of salts by size exclusion correlated with removal of pathogens.	A value related to the presence of charged species in water.
Oxidation-reduction potential (ORP)	Ozonation Chlorination Other chemical oxidation Advanced oxidation	High ORP values are representative of strong oxidative environments where pathogens can be destroyed due to chemical oxidation.	A measure of the gain or loss of electrons from chemical species in a liquid sample.
Ozone residual	Ozonation	The product of residual concentration of ozone and total contact time correlates with the reduction of some pathogens or biological surrogates.	The concentration of ozone in water following a given reaction period.
Particle size distribution	Sand filtration Cartridge filtration Membrane filtration	The absence of particles in a particular size range correlates with removal of pathogens in similar size ranges.	The size classification of suspended particles in a liquid sample.
pH	Chlorination	The pH of a solution can affect the performance of chemical treatment processes, such as chlorination.	The inverse log hydrogen ion concentration of a solution.
Pressure decay test	Membrane filtration	Damage to the membrane surface will result is the passage of particles larger than the nominal pore size and alter the characteristic pressure decay for the membrane.	Surrogates used as indirect measure of membrane integrity.
Total organic carbon and UV absorbance (254 nanometers)	Reverse osmosis Advanced oxidation processes	Total organic carbon correlates to the degree of treatment and biological stability of water.	A measure of the residual aggregate organic constituents in water measured as carbon.
Turbidity	Sand filtration Cartridge filtration Membrane filtration	The presence of turbidity following filtration processes is indicative of potential pathogen breakthrough.	Suspended particulate matter measured by detecting reflected light.
UV intensity	UV disinfection	The intensity of UV energy measured near the reactor wall can be affected by factors like UV absorbance, lamp output, and sleeve fouling.	Removal of pathogens correlated with UV dose.

[a] Adapted from Tchobanoglous et al. (2015).

CHAPTER 7

Storage, Distribution, and Use of Water from Decentralized Non-Potable Water Systems

7.1 Overview

To achieve the desired objectives of public health protection, treated water must be properly stored and distributed to prevent compromising the quality of water after treatment. For example, opportunistic pathogens like *Legionella* (Beer et al., 2015) could grow in the distribution system, sewage could contaminate treated water (Besner et al., 2013), or lead and copper (which cause toxicity) could leach from piping (U.S. EPA, 1991). Consequently, it is essential to manage carefully and thoroughly all potable water services to the point of ingestion, inhalation of aerosols, or direct and indirect human contact. Municipal reclaimed water systems recently began focusing on best management practices for water storage and distribution, an area studied widely for potable water (Jjemba et al., 2015). DNW systems face similar management challenges as reclaimed water, and can benefit from best management practices modified to address the unique characteristics of non-potable water.

Centralized drinking water systems manage enteric (fecal) pathogens relatively well, and the same is true for DNW systems if the LRTs described in Chapter 3 are met. The largest recognized cause of waterborne risk from drinking waters in the United States is premise-plumbing growth of *Legionella*, which causes hundreds of millions of dollars in hospitalization costs each year (Collier et al., 2012). The current scientific understanding of *Legionella* growth in piped waters is that most amplification (to problematic concentrations) occurs within amoebae that feed on pipe biofilms (Ashbolt, 2015). A single thermal or disinfection shock may remove biofilm-released pathogens, but not the source of the problem (i.e., the biofilm niche). Hence, new plumbing systems should not be allowed to stagnate prior to use (i.e., between construction and occupants using a system), nor should ongoing systems ignore best management practices until significant biofilm mass develops. At this point, it is too late to control *Legionella* without regular and extensive cleaning protocols. Producing adequate quality non-potable water that meets all the pathogen control criteria set forth in this report is the first step in ensuring proper public health protection. The final step in quality control is to manage properly 1) storage and distribution systems and 2) the uses of non-potable water.

In DNW systems, neither significant/routine ingestion nor direct contact with the treated water product is anticipated due to limited exposures to non-potable water. Nevertheless, the occurrence of aerosol inhalation and indirect contact requires the careful management of DNW system storage and distribution systems to control exposures to non-tuberculous mycobacterial and *Legionella* pathogens (Ashbolt, 2015). For example, even clean drinking water may allow biofilm growth of *Legionella* (aerosol pathogen risk) if the water temperature is between 25 to 45°C and stagnates, resulting in the presence of minimal residual chlorine.

The water industry now bases best management practices on a hazards analysis critical control point (HACCP) system. Possible hazards and corresponding control points are identified throughout the system and appropriate monitoring is undertaken to proactively maintain control of the system

(NWQMS, 2006). WHO also promotes the HACCP approach through its Water Safety Plans and Sanitation Safety Plans (WHO, 2009).

7.2 Best Management Practices for Storage and Distribution

A number of approaches are available to control microbial regrowth in distribution systems, each with varying benefits and drawbacks that depend on the characteristics and use of the system. See Table 7-1 for recommended approaches.

Table 7-1: Recommended Approaches for Controlling Microbial Growth in Distribution Systems

Approach	Description
Producing non-potable water low in carbonaceous material and nutrient content	The primary energy source for pathogen regrowth is organic carbon measured as assimilable organic carbon, biodegradable dissolved organic carbon, total organic carbon, and other essential nutrients, including nitrogen (N), phosphorous (P), and iron (Fe); therefore, the primary means to reduce the regrowth potential of pathogens is to provide highly treated water. Reducing the potential for regrowth is more important in large-scale buildings or neighborhood/district-scale projects where there will be more residence time (creating more opportunities for regrowth) in distribution systems that supply non-potable water.
Producing highly disinfected non-potable water	Low concentrations of microbes resulting from filtration and advanced means of disinfection have a reduced potential for regrowth if organic carbon levels are low. Otherwise, there may be a need for a residual disinfectant to manage growth in larger community systems that produce aerosols. Post-treatment disinfection with ultraviolet (UV) radiation is a recommended means of disinfection that does not increase levels of assimilable organic carbon or biodegradable dissolved organic carbon.
Using non-reactive, biologically stable materials of construction	Avoid the use of corrosive materials or organic materials that tend to protect microorganisms from disinfection and enhance the regrowth environment by the adsorption of organic compounds (LeChevallier et al., 1990).
Maintaining a residual disinfectant	Different disinfectants offer advantages and disadvantages to overall water quality and system management. In general, a higher disinfectant residual provides lower regrowth. Many design and operation considerations are available for each specific system. The Panel recommends that a free chlorine residual of 0.2 milligram per liter (mg/L) (Cervero-Arago et al., 2015) or monochloramine residual of 2 to 3 mg/L (Marchesi et al., 2013) be maintained at or near the point of use to control microbial growth. Using disinfectant booster stations within the distribution system is one way to ensure adequate disinfectant residuals for systems with long detention times. Chloramine provides a better residual duration as compared to chlorine. Various combinations of UV, chlorine, chloramine, ozone, and hydrogen peroxide are beneficial for specific disinfection goals. Periodic shock treatments with disinfectants and continuous disinfection looping of reservoirs help reduce the potential for regrowth and manage issues with biofilms (LeChevallier, 2003). Stagnation resulting from dead zones or prolonged periods of zero-flow or low flow that create long residence times and allow disinfectants to dissipate and sediments to deposit result in improved conditions for regrowth and should be avoided.
Cleaning storage tanks	The required frequency of storage tank cleaning varies depending upon the quality of water stored, detention time in storage, temperature of the water, and nature of the tank. Tanks that are open to the atmosphere require more frequent cleaning.
Flushing the distribution system	The required frequency of distribution system flushing varies depending upon the quality of water transmitted, detention 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 must include means for easily flushing pipes as part of routine maintenance.
Controlling temperature	Avoid the storage and distribution of non-potable water within 20 to 45°C (Health and Safety Executive, 2013d) to reduce the potential for pathogen regrowth. Otherwise, consider a disinfection residual or point-of-use system, particularly if aerosols are generated. Heat recovery from warm waters, particularly graywater and wastewater, can offer the benefit of reducing the temperature at which these waters are stored.

7.3 Distributing Non-Potable Water with Fire Suppression Systems

The use of fire suppression piping within a building or district as a non-potable water conveyance system has merit and is practiced in some instances. This dual-purpose approach offers savings for capital and operating costs, and establishes a means of providing routine water quality management that is beneficial to all uses of non-potable water, including firefighting. Typically, the water within a traditional fire suppression system is considered non-potable because of long stagnation periods that result in the loss of residual disinfectants and the buildup of contaminants and sediments due to corroding and deteriorating construction materials or the addition of chemicals to prevent freezing. Providing continuous flow offers system management and water quality benefits for firefighting purposes; however, fire flow requirements must be addressed within system design, abide by applicable fire system codes, and receive approval from the local fire official.

The specifics of a fire suppression system will considerably influence the design and operation of a DNW system. Storage reservoirs and piping sizing and configuration must ensure that non-potable fixtures do not compromise flow during a fire. To protect firefighters, it is necessary to ensure aerosols and the inadvertent consumption of water are not harmful and are within appropriate risk criteria. A system with hose stanchions (which can sometimes serve as a source of drinking water during a fire) may require signage or other special features to avoid unnecessary exposures.

7.4 Roles and Responsibilities for Storage and Distribution Systems

Under current potable water supply practices, the management responsibilities of the potable water utility typically terminate at the water main in the street or at the water meter entrance to the customer's building. The property owner often is responsible for managing the service lateral between the water main in the street and the building, as well as the plumbing inside the building. Per RME Management Categories 1 and 2, as described in Chapter 2, the building owner serves as the RME, with no consideration given for dividing responsibilities. The building owner has full responsibility. For RME Management Category 3, however, the division of responsibilities between the RME and building owner requires further consideration and must be defined clearly.

The division of responsibilities for RME Management Category 3 systems will vary depending on the nature of the specific system. In general, the sole responsibility of the RME ends at the storage reservoir (if located within the building) or distribution main in the street (if the storage reservoir is offsite), similar to the configuration of a typical public potable water supply system. It may be necessary, however, to extend the responsibility of the RME to include portions or the entirety of the indoor non-potable water plumbing to provide professional management of the system up to (and possibly including) the plumbing fixtures.

A logical example of shared responsibility is the case of non-potable water supply for cooling towers. In this case, the RME may ensure that non-potable water meets specifications and the storage and distribution system up to the cooling tower meet best management practices. The owner, then, is responsible for the O&M of the cooling tower and associated water quality controls, which often are connected to non-potable water feed mechanisms. For buildings with a "condominium" form of ownership, it may be logical to consider a more extensive role for the RME. In this case, sharing responsibility for the indoor non-potable water plumbing might include having the RME be responsible for the system up to the entrance of each condominium unit and individual unit owners being responsible within their own properties.

Many combinations of roles and responsibilities are viable, provided they are defined clearly and understood by all parties involved. The local regulator may want to dictate how to assign these roles and responsibilities, or rather may want to simply ensure they are assigned clearly and well understood via documentation. This matter should be addressed in the PAR described in Chapter 8.

7.5 Considerations for *Legionella*

The DNW system RME, designer, and operator each should review published guidelines for the management of *Legionella* in distribution systems and implement as appropriate for each specific system. In particular, *ANSI/ASHRAE Standard 188-2015 Legionellosis: Risk Management for Building Water Systems* (2015) provides guidance on best management practices for both potable and non-potable water systems. It addresses management program responsibilities, system design, risk analysis, control mechanisms, monitoring, confirmation, and documentation. The publication *Legionnaire's Disease: The Control of* Legionella *Bacteria in Water Systems* is a comparable and worthwhile reference that sets forth the Approved Code of Practice in the United Kingdom (Health and Safety Executive, 2013a). Both documents focus on appropriate risk mitigation for potable and non-potable water systems and require analyses of fixtures and uses. Although both the ASHRAE Standard and HSE Code of Practice target legionellosis, their rationales and approaches are applicable to all pathogens and health risks identified in this report.

CHAPTER 8

Permitting and Reporting for DNW Systems

The purpose of the PAR is to describe the project and identify how it complies with each regulatory requirement of the regulatory jurisdiction(s), providing the information needed to effectively evaluate and permit the project.

Many topics addressed herein may not be appropriate for projects that pose little risk to users (e.g., projects using relatively uncontaminated sources or involving uses with low public exposure). The scope of a PAR is dictated by the regulatory requirements for its specific type of project. A Management Category 3 project (see Chapter 2) may need to address all or most sections included in a PAR, whereas a Management Category 1 project might be allowed to dispense with entire sections of the PAR (e.g., provision for outages, commissioning plan) and provide an abbreviated version of other sections.

Regulatory evaluation and permitting of a complex project may be conducted in stages, similar to what is done when developing a new public water system source or upgrading a wastewater treatment plant. The regulator could grant preliminary approval of a project concept based on the draft PAR. Once there is agreement on the use and treatment of the source water, the RME can develop the final PAR, which would include plans and specifications, a commissioning plan, and an O&M plan. Final regulatory approval of the project will depend on the acceptance of all plans and schedules by the regulatory authority. If some conditions or necessary requirements of a project are not fully resolved, a limited-term permit may be necessary. See Table 8-1 for a summary of the process used for PAR submittal, required demonstrations, and project review.

The minimum required qualifications for the person(s) preparing the PAR should be identified. The Panel recommends that a Registered Professional Engineer with the appropriate expertise prepare the PAR.

Table 8-1: Reports Submitted and Issued as Part of the Process to Approve a Decentralized Non-Potable Water System

	Report/Document	Description
Submitted	Draft Permit Application Report	Includes proposed uses and treatment (if this step is allowed by the jurisdiction's process and is justified by the complexity of the project).
	Final Permit Application Report	Includes plans and specifications, a commissioning plan, and an operation and maintenance plan.
	Facility Commissioning Report	Includes results from field verification and a final monitoring plan.
Issued	Permit decision document	
	Monitoring requirements	

8.1 Permit Application Report Elements

The recommended components of a PAR are described in Sections 8.1.1 to 8.1.9.

RECOMMENDED COMPONENTS OF A PERMIT APPLICATION REPORT

- Responsible management entity.
- Project overview.
- Relevant regulations.
- Water source.
- Treatment processes.
- Reliability.
- Water uses.
- Cross-connection control.
- Water quality and $\log_{10}$ reduction value monitoring.
- Facility commissioning plan.
- Operation and maintenance plan.
- Provisions for water quality exceedances, power outages, spills, and other emergencies.

8.1.1 Responsible Management Entity

This section is used to describe and clarify the RME and its Management Category (see Chapter 5 for more information).

☑ Identify and describe the RME, as well as identify and justify its Management Category.

☑ Demonstrate the RME has the technical, managerial, and financial capability to build and operate the proposed project in conformance with all relevant regulations.

☑ When more than one entity is involved, describe the roles and arrangements of each for coordinating activities. The division of roles and responsibilities must address the management of the distribution system and indoor plumbing. An organizational chart may be necessary. The regulator may ask for a contract between the multiple entities to clarify the responsibilities of each.

8.1.2 Project Overview

Background is needed on the project itself, as described in this section.

☑ Identify the nature of the water source, treatment proposed, water use, and use area.

☑ Present an estimated schedule for project implementation that considers the building construction schedule.

8.1.3 Relevant Regulations

The following steps are necessary to ensure the RME understands what requirements must be satisfied, as well as serve as a framework for demonstrating how to meet the requirements consistently.

- ☑ Identify all requirements for wastewater management, water reuse, and plumbing that apply to the project.
- ☑ Identify the municipal water and wastewater entities that will connect to the DNW system.

8.1.4 Water Source

This section is used to clarify and document the source of water and any associated issues or challenges.

- ☑ Describe the source of water, raw water quality, and expected demand flow for the project.
- ☑ Identify the hydraulic and contaminant loading rates of the proposed facilities to enable an evaluation of the adequacy of the design of the DNW system.
- ☑ Describe the origin of the source water(s) so that the potential for contaminant loading is understood.
- ☑ Identify the range of flows that could be observed.
- ☑ Provide the raw water quality characteristics (i.e., typical values and range) that will govern the design of the proposed treatment processes (e.g., biochemical oxygen demand for biological processes and suspended solids for filtration).

8.1.5 Water Treatment

The purpose of this section is to demonstrate that the treatment scheme will meet requirements for water quality and treatment specific to its type of project.

- ☑ Describe the processes used to achieve each water quality or treatment requirement.
- ☑ Include a schematic of the proposed treatment train.
- ☑ Describe each treatment process, addressing design criteria, selected equipment, loading rates, contact times, filtration media, and chemicals used.
- ☑ Describe any chemical storage and feed equipment.
- ☑ Identify the source of power required for treatment.
- ☑ Describe the means of handling treatment residuals.
- ☑ Provide evidence that the proposed treatment scheme will achieve the water quality or treatment objective (e.g., treatment certification, validation report, performance studies, or accepted treatment LRV listing). This evidence may be based on studies completed for other projects or in other jurisdictions. For projects in higher level Management Categories, the jurisdiction should expect a treatment LRV validation or performance study that:
    1) Is conducted by a Registered Professional Engineer experienced in water treatment.
    2) Uses a protocol approved or accepted by the controlling jurisdiction.
    3) Identifies the LRV achieved 95% of the time (fifth-percentile LRV) or other standard adopted by the jurisdiction.
    4) Verifies LRV performance during the commissioning study.

8.1.6 Reliability

The entire project must function to reliably produce and deliver water that meets water quality objectives and is safe for its intended uses; therefore, the plan for ensuring total system reliability must address treatment effectiveness, process and water quality monitoring, operations and control, contingency control and response, and the safe delivery and use of the water.

- ☑ Describe how the treatment is designed, operated, and maintained to produce finished water that meets the necessary water quality objectives. The fraction of time that water quality or treatment does not fall below specified objectives is defined as "dependable." If the jurisdiction has not identified what dependable means, treatment should be designed and operated to achieve the required LRV 95% of the time.
- ☑ Describe how the equipment used to monitor treatment, operations, and water quality enables determination of whether the system is working as planned. A rapid online method, possibly monitoring one or more surrogate parameters, should be used to control the treatment operation and flow of water to the use area.
- ☑ Describe how the monitoring and controls of the system will enable the operator or automatic controls to intervene in the event of the production of off-specification water.
- ☑ Include an evaluation of the potential for contingencies that reasonably could disrupt operation (e.g., power failures, vandalism, and excessive source contamination) and provide remedies.
- ☑ Describe the surveillance program for the distribution and use area to minimize the potential for unplanned access to or use of the produced water.

8.1.7 Water Uses

An understanding is needed of the use(s) of the water to properly evaluate public exposure and the necessary requirements to protect public health.

- ☑ When irrigation is planned, describe the types of vegetation involved.
- ☑ Where plumbing fixtures are served, describe the kinds and locations of fixtures used.
- ☑ Describe the contents and locations of public signs.
- ☑ Describe the process for customer notification and education regarding the use of the water.
- ☑ Provide a list of the use sites, with a description of distribution plumbing (a map or diagram should be required).
- ☑ Describe public access to the use area.
- ☑ Describe land use surrounding the use area, if outdoors.

8.1.8 Cross-Connection Control

The potential for the inadvertent introduction of non-potable water into plumbing for potable water must be controlled. Cross-connections of alternative water source with the potable system could occur at the conveyance of source water to the treatment, at the treatment facilities, as the non-potable water is distributed to the use area, and where provision is made for a back-up supply when the project is out of service. This section should address:

- ☑ The responsible parties for cross-connection control.
- ☑ Control during construction, including inspection and documentation.
- ☑ Plumbing system design and proximity to potable water plumbing.
- ☑ Control of access to the plumbing.
- ☑ Inspection and documentation of all plumbing construction and modifications.
- ☑ Back-up supply or other procedures for outages.
- ☑ Backflow prevention devices and assemblies.
- ☑ Backflow inspections and tests, including frequencies and by whom.
- ☑ Qualifications required of inspectors and testers.
- ☑ Training or procedures to advise system operators and users of the threat of, and means to avoid, cross-connections.
- ☑ Access for inspections, including consent (i.e., permissions and design considerations).

8.1.9 Provisions for Outages

Provisions should be made to prepare for system outages, specifically contingencies to handle a loss of service due to planned or unplanned shutdowns of the project.

- ☑ Identify any alternative sources of water to supply the use.
- ☑ Describe how the alternative sources will connect to the use, including backflow prevention equipment and procedures.
- ☑ If an alternative source of water is not available during outages, identify any actions needed to accommodate or notify end users.

8.1.10 Plan for Excess or Inadequately Treated Water

A safe manner is needed to manage water produced in excess of the quantity used or water that does not meet quality or treatment requirements.

- ☑ Describe the process used to decide when to divert water, controls needed to do so, and ultimate destination of the unusable water.

8.2 Additional Plans and Schedules

A complete project application should include plans and specifications, a facility commissioning plan, and an O&M plan, each in sufficient detail to allow regulators to determine compliance with requirements.

8.2.1 Plans and Specifications

Provide design drawings, plot plans, and specifications that address all regulated aspects of the DNW system. The project components that may require plans and specifications include source collection and conveyance, treatment, instrumentation and controls, water distribution, use area, interconnections with other water supplies, and facilities for handling unusable water.

8.2.2 Commissioning Plan

A demonstration that treatment and other facilities will function as intended should be required. It is important that treatment meets objectives, instrumentation accurately indicates treatment performance (including treatment failures), and plumbing is pressure-tested to show it is free of cross-connections. See Table 8-2 for an example of activities that may be involved in DNW system commissioning.

Facility commissioning can occur before or concurrently with the Field Verification discussed in Section 6.3 of Chapter 6. Conduct a commissioning demonstration at the initial operating and build out (design) of hydraulic and contaminant loading rates. Testing should be scheduled (or rescheduled, if necessary) to address treatment processes that require time to stabilize. The demonstration test period should be long enough for treatment processes to reach steady operating conditions and to experience at least one cleaning or backwash cycle (where appropriate). Collect sufficient performance data to determine that treatment meets reliability requirements (i.e., the fraction of time that various objectives must be met) for compliance (see Section 6.3 of Chapter 6).

The commissioning plan should specify the following:

- Hydraulic and contaminant load during the test.
- Location and schedule for all sampling or measurements.
- Methods used to analyze samples or make measurements.
- Person(s) responsible for conducting the test and processing samples.
- Method used to verify that the required LRVs are achieved.
- Test plan for the monitoring, alarm, and control systems.

8.2.3 Operation and Maintenance Plan

Project facilities and treatment processes will not achieve regulatory and water quality objectives unless they are operated and maintained properly. The purpose of the O&M plan is to 1) provide procedures for facility operators to safely and effectively operate and maintain the facilities and to 2) give regulators confidence that the project will satisfy regulatory requirements. Facilities must be operated and maintained in conformance with the approved O&M plan. See Table 8-3 for a list of elements to address in the O&M plan.

Table 8-2: Examples of Considerations for Facility Commissioning

Item	Features to Be Confirmed During Commissioning
Influent/raw water	• Regularly service automatic diversion or first flush devices. • Characterize influent constituent concentrations.
Natural and biological treatment	• Review and finalize the operation and maintenance (O&M) plan. • Field verification of $\log_{10}$ reduction values (LRVs). • Develop process O&M logs.
Filtration systems	• Review and finalize the O&M plan. • Verify process controls, such as coagulants and filter cycles (media filtration). • Test the integrity of membranes. • Field verification of LRVs. • Develop process O&M logs.
Disinfection systems	• Review and finalize the O&M plan. • Field verification of LRVs. • Conduct tracer testing of reactor hydraulics. • Develop process O&M logs.
Sensors	• Conduct an audit of service needs. • Confirm sensor calibration procedures. • Check sensor verification procedure against a reference standard.
Controls and telemetry systems	• Finalize definitions for out-of-specification performance for all parameters with continuous monitoring and control. • Check integrity and scaling of data outputs. • Verify system alarm functions. • Verify that the Responsible Management Entity (RME) is connected to and receiving monitoring data. • Check system alarms and telemetric monitoring systems; quality assurance/quality control (QA/QC) check of logged data.
Distribution (note: most plumbing checks must be done before construction is complete)	• Assess fixtures for operation and compatibility. • Check entire system for cross-connections. • Check post-processing systems for corrosion control. • Check that the labels for all piping and fixtures are accurate. • Check pressure set points.

Table 8-3: Elements of an Operation and Maintenance Plan

No.	Operation and Maintenance (O&M) Element
1	The means used to verify that requirements for microorganism reduction are met.
2	A description of how each treatment process will be operated, including: • Acceptable treatment performance reliability and triggers for shutdown or other operator intervention. • Procedures for setting chemical feed rates and triggers for adjusting the feed rate. • Identifying when backwash or equipment cleaning is required and identifying the procedure.
3	A description of instrumentation, including: • Instrument use. • Alarms (identify where monitored). • Schedule for instrument calibration and maintenance (identify any deviation from manufacturer recommendations). • Instrument calibration and maintenance procedures (identify any deviation from manufacturer recommendations).
4	A water quality monitoring plan informed by Sections 6.4 and 6.5 of Chapter 6 that includes a monitoring schedule identifying the methods and monitoring locations.
5	A monitoring system quality assurance plan that structures the monitoring and data management program (to ensure data of acceptable quality), including: • Assigning the responsible management entity (RME). • Training the RME in process operations and monitoring. • Using chain-of-custody procedures. • Maintaining accurate records. • Auditing field and sampling activities. • Determining sampling frequency and data quality. • Identifying circumstances necessitating regulator notification, and providing the notification procedures and regulator contact information.
6	A monitoring system quality control program for implementing measures to ensure the integrity of the data being collected that reflects the quality assurance plan and includes: • Regular calibration of continuous monitoring equipment. • Scheduled service intervals for process and monitoring equipment. • Maintaining chemicals and reagents within expiration dates. • Use of duplicate, replicate, blank, and spiked samples.
7	Routine maintenance schedules and methods for all facilities.
8	Triggers for unscheduled maintenance.
9	Operator qualifications and training to ensure the proper operation, maintenance, and monitoring of treatment and other facilities. Educational requirements, vocational certification, or other indications that the operator has the capacity to assimilate and apply training are particularly useful. The Panel recommends training specific to actual equipment used. Training on the public health consequences of treatment failures and cross-connections is important.
10	Operator schedules for remote and onsite operation.
11	Any arrangements for contract operation.
12	Training requirements for plumbers connecting the uses.

No.	Operation and Maintenance (O&M) Element
13	A contingency plan in the event of a treatment failure to prevent the delivery of inadequately treated water to the use area.
14	Manufacturer cut sheets and O&M manuals.
15	Equipment service contracts.
16	Sample water treatment surveillance and monitoring data sheets.
17	A sample monthly compliance determination sheet.
18	A sample log sheet for maintenance.
19	User and public information, including: • Signage, pamphlets, and/or other educational materials that inform users of non-potable water usage and provide best practices to ensure system reliability. • Signage or other posting should conform to relevant local ordinances.

8.3 Commissioning Report

A report presenting the results of the facility commissioning demonstration, including field verification (when required), should be submitted to the regulatory authority. The report should identify deviations from the commissioning plan, efficacy of treatment, and any situations resulting in out-of-specification performance, as well as characterize the ability of the project to comply with all permit requirements. A final monitoring plan should be included that specifies criteria for defining out-of-specification performances of unit processes. The Commissioning Report also should include the results of the following:

- Checks for cross-connection.
- Pipe labelling.
- Functionality of unit operations (e.g., pumping, aeration, level controls, chemical feed rates).
- Electrical components.
- Online instrumentation and alarm response.

8.4 Review and Approval of Permit Application Reports and Commissioning Reports

A trained group of professionals should review and approve PARs and other reports required for project approval. The regulating jurisdiction or a third party authorized by the jurisdiction should undertake this review. In time, a program may be established to provide certification for DNW system reviewers that would ensure third-party reviews are conducted by qualified professionals.

The jurisdiction should identify the expertise needed for reviewing PARs and determine the necessary qualifications. Reviewers with knowledge of cross-connection control practices, environmental health, onsite wastewater systems, and water treatment design and operation are appropriate. It may be necessary to have a Registered Professional Engineer review a submittal prepared by another Registered Professional Engineer.

8.5 Record Retention and Reporting

The regulatory authority should require that compliance monitoring and calculations be reported at least annually. Projects in higher Management Categories may need a higher frequency of reporting. Violations and incidents that may indicate a risk to the public (e.g., suspected cross-connections, treatment bypasses, or reports of illness) should be reported promptly. Requirements should specify the retention schedule for compliance reports, monitoring data, significant maintenance activities, and unusual operational incidents.

Routine reports should include all information necessary for determining compliance with the requirements appropriate to the type of project, which may include:

- Results of verification monitoring and calculations.
- Water quality analyses.
- Significant maintenance activities.
- Treatment modifications.
- Outages (including reasons and durations).
- Cross-connection tests and inspections.

8.6 Pre-existing Approved Decentralized Non-Potable Water Systems

Options for addressing projects approved under previous criteria and permit procedures will depend on the authority of the jurisdiction to revisit approvals, policies and priorities for bringing activities into compliance with upgraded requirements, and resources available to do so. Evaluating and re-permitting projects should be prioritized based on the Management Category for the project (see Chapter 2). Also important is the suitability of the original permitting and surveillance approach and whether that approach is deemed appropriate to ensure public health targets are achieved. Options for addressing preexisting projects include:

- **Evaluate projects on a case-by-case basis.** Depending on the original permitting and surveillance approach, there may be useful experience with how well the facilities and system management are protecting the public. Such experience can help determine the extent of the necessary permit application and permit upgrade. If extensive water quality monitoring was required in the original permit, then the RME could continue with its extensive monitoring and reporting program or submit a PAR that demonstrates the LRTs are achieved by the system in place and move to the new monitoring regime.

- **Put projects on a schedule to reapply or have the permit renewed using the new requirements.** The schedule would reflect the priorities and resources of the regulator. As an example, the schedule can be unhurried for Management Category 1 and 2 (i.e., lower risk) projects. For projects where some permit action is desirable or due, the permit could be renewed for a limited term, possibly with enhancements based on this framework.

- **Grandfather all or some projects.** Regulators should develop criteria for grandfathering projects (i.e., exempting existing projects from new laws or regulations). Management Category 1 projects might be good candidates for grandfathering, whereas Management Category 3 projects could pose sufficient public risk to justify imposing new requirements. The Panel does not recommend grandfathering projects unless the project poses a risk to the public no greater than the tolerable risk identified by the jurisdiction. Notify water users that it is a grandfathered system.

CHAPTER 9

Example Applications of the Framework for Decentralized Non-Potable Water Systems

As described in Chapter 2, the risk-based framework and associated guidance for a particular non-potable water scheme consists of the following:

- Selecting the appropriate estimated baseline levels of viral, bacterial, and protozoa data for the source water.
- Determining the estimated LRTs, expressed in log_{10} units, for the specific pathogen and assumed end-use exposure.
- Specifying appropriate surrogates and operational parameters that represent the anticipated log_{10}-reduction of key potential pathogens.

Surrogates and other operational parameters for the water system are documented in the monitoring plan (see Chapter 6) and included in the PAR (see Chapter 8). Examples of DNW systems using different source waters for different end uses are provided in this chapter to demonstrate the application of information presented in this report. Refer to Table 9-1 for the general procedure to evaluate DNW systems.

EXAMPLES OF DNW SYSTEMS USING DIFFERENT SOURCE WATERS FOR DIFFERENT END USES

- Example 1: Roof runoff for toilet flushing.
- Example 2: Reuse of Heating, Ventilation, and Air Conditioning (HVAC) condensate in a cooling tower.
- Example 3: Analysis of blackwater reuse for toilet flushing.
- Example 4: Simple graywater system for toilet flushing.
- Example 5: Stormwater for landscape spray irrigation.
- Example 6: Wastewater reuse for toilet flushing, laundry, and cooling.

Table 9-1: Steps in the Preliminary Evaluation of Decentralized Non-Potable Water Systems

Step	Description
1	Identify the Management Category and $\log_{10}$ reduction targets (LRTs) for the reference pathogen groups using information provided in Chapters 2 and 3.
2	Evaluate the proposed treatment process to achieve the LRTs using Chapter 4 as a preliminary guide.
3	Designate the requirements for the Responsible Management Entity (RME) using information provided in Chapter 5.
4	Develop a monitoring plan for the proposed non-potable use with information provided in Chapter 6.
5	Develop best management practices for the proposed non-potable use with the information provided in Chapter 7.

Example 1: Roof Runoff Use for Toilet Flushing in a Multi-User Building

In Australia and other countries, it is common to use roof runoff as a non-potable water supply in which there is little to no treatment due to its high purity compared to other non-potable sources of water. Rainwater-derived sources, however, necessitate special considerations when used in buildings for toilet flushing, such as the potential for pathogenic bacteria originating from animal feces, corrosion of metallic plumbing components (e.g., low pH source water), and development of opportunistic pathogens if the temperature of water in storage tanks or plumbing systems rises over the threshold of 25°C. See Figure 9-1 for an illustration of the procedure to evaluate toilet flushing with roof runoff.

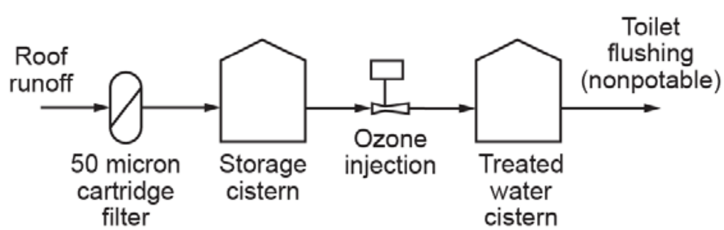

Figure 9-1: Proposed treatment train for a roof runoff source used for toilet flushing (Example 1).

Step 1. Identify the Management Category and Log_{10} Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, the use of roof runoff in a non-single family building is specified as Management Category 2. The LRTs for alternative source waters and reuse applications from Table 3-3 in Chapter 3 are summarized in Table 9-2, in which enteric bacteria are the primary pathogen group.

Table 9-2: Summary of Log_{10} Reduction Targets for Flushing Toilets with Roof Runoff (Example 1)

Pathogen Group	Log_{10} Reduction Target
Enteric viruses	Not applicable
Parasitic protozoa	No data
Enteric bacteria	3.5

Step 2. Evaluate the Proposed Treatment Process to Achieve the Log_{10} Reduction Target

Using information from Table 4-5 in Chapter 4, an ozone system with a CT value of 0.04 mg • min/L can achieve 4-log_{10} reduction of enteric bacteria.However, the 50-micron prefilter does not provide an adequate level of filtration to inactivate embedded and shielded pathogens. For effective ozonation, the Panel recommends an additional 10-micron cartridge filter. Alternative treatment trains that also could meet the required LRT include:

- Microfiltration (i.e., >6-log_{10} reduction of bacteria).
- Sand filter with an equivalent effluent particle size distribution of 10 microns, followed by UV radiation with a dose of 30 to 45 mJ/cm^2 (i.e., 4-log_{10} inactivation of bacteria).
- Cartridge filtration (10 microns), followed by UV disinfection (30 to 45 mJ/cm^2) or chlorination with free chlorine with a CT value of 1.6 to 2.4 mg•min/L (i.e., 4-log_{10} inactivation of bacteria).

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, roof runoff for toilet flushing in a multi-user building should have an RME designated as Management Category 2. Although opportunistic pathogens like *Legionella* do not have specified LRTs, it is important to recognize how to minimize their growth (see Step 5).

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

The monitoring plan will depend on the type of treatment technologies used, designated Management Category of the RME, and system-specific considerations. Some example monitoring plans include:

- **Validation testing.** The use of processes for pathogen control that have validated LRVs are recommended for Management Category 2 systems.
- **Field verification.** Challenge testing at key PCPs should be performed at Management Category 2 systems. Surrogates for bacterial pathogens may include *E. coli*, *B. diminuta*, or *R. terrigena*.
- **Continuous verification monitoring.** Continuous monitoring at PCPs is required for Management Category 2 systems. For the technologies proposed in Step 2, recommended control points for continuous process verification include turbidity entering the ozone system and ozone residual or oxidation-reduction potential after ozonation.

Other parameters for continuous process monitoring, such as pH, temperature, and differential pressure, can improve process reliability. See Table 2-4 in Chapter 2 for a summary of recommended design and control features.

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For non-potable water systems, consider the chemical characteristics of roof runoff and storage conditions, as follows:

- Due to its high purity, roof runoff may result in the corrosion of components and fixtures of the metallic distribution system. If any metallic pipe, fittings, solder, or fixtures are used that may be subject to corrosion from contact with aggressive water, then modify the water system or add a corrosion inhibitor to the non-potable water supply.

- If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 milligrams per liter (mg/L) or chloramine residual of 0.5 mg/L (Cervero-Aragó et al., 2015) at or near the point of use.

Example 2: Heating, Ventilation, and Air Conditioning Condensate Reuse in a Cooling Tower

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Example 2 illustrates the process for evaluating, designing, and managing a multi-user system that collects HVAC system condensate. Because HVAC system condensate comes from atmospheric moisture, it is essentially distilled water with a low mineral content, which is corrosive to metals (particularly steel and iron). Typically, HVAC condensate is collected in open drip pans, making it susceptible to contamination with airborne bacteria like *Legionella*. Condensate drip pans also may be exposed to rodent feces, thereby containing fecal coliform bacteria that may indicate the presence of bacterial pathogens such as *Salmonella* or *Campylobacter* spp. Rodents also may excrete leptospira bacterial pathogens in their urine.

Step 1. Identify the Management Category and Log_{10} Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, the use of condensate in a multi-user building is specified as Management Category 2. HVAC condensate is not expected to be directly contaminated by human enteric pathogens, but rather it can support the growth of potential opportunistic bacterial pathogens. There is no LRT, although the requirements for spray irrigation should be consulted if the potential exists for the transport of aerosols. Best management practices are required to minimize the growth of opportunistic bacteria, along with appropriate protection from atmospheric fallout of dust and/or contaminated aerosols.

Step 2. Evaluate the Proposed Treatment Process to Achieve the Log_{10} Reduction Targets

For multi-user building applications, if the condensate is within the temperature window for opportunistic bacterial growth (25 to 45°C), it may be appropriate to add a residual disinfection step prior to distribution. A free chlorine residual of 0.2 mg/L (Cervero-Arago et al., 2015) or monochloramine residual of 2 to 3 mg/L (Marchesi et al., 2013) at or near the point of use can control microbial growth.

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, the condensate used for cooling applications in a multi-user building should have an RME designation as Management Category 2. Although opportunistic pathogens like *Legionella* do not have specified LRTs, it is important to know how to minimize their growth and provide an appropriate management plan for their control (see Step 5).

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

As discussed in Chapter 6, the monitoring plan will depend on the type of treatment technologies used, designated Management Category of the RME, and system-specific considerations. Some example monitoring considerations include:

- **Field verification.** Challenge testing for PCPs is recommended for Management Category 2 systems; however, the growth of heterotrophic bacteria is a general indicator of biologically unstable water, and if water temperature is 25 to 45°C, then *Legionella* and other opportunistic pathogens may grow to levels of concern. Grab sampling for the presence of heterotrophic bacteria (HPCs) above 500 per 100 mL would indicate problematic growth conditions.

- **Continuous verification monitoring.** Continuous monitoring of PCPs is required for Management Category 2 systems. In this case, monitoring the concentration of the residual disinfectant should be sufficient to control the growth of opportunistic pathogens.

Refer to Table 2-4 in Chapter 2 for a summary of additional recommended design and control features.

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For the use of condensate in a cooling tower, the most important considerations are related to the management of the distribution system, as follows:

- **Corrosion.** Due to its high purity, condensate may corrode metallic distribution system components and fixtures. If any metallic pipe, fittings, solder, or fixtures are used that may be subject to corrosion from contact with aggressive water, then modify the water system or add a corrosion inhibitor to the non-potable water supply depending on the nature of the non-potable water use. In addition, piping and evaporative coils may include lead solder, which could cause build-up of lead concentrations (and needs to be considered based on the specific cooling use of the non-potable water).

- **Disinfection.** Condensate production in cooling units and collection in condensate drains can be slow, thereby allowing stagnation and lengthy exposure to warm air. Because *Legionella* and other opportunistic bacterial pathogens could grow within a condensate water system, appropriate consideration must be given to disinfecting condensate during storage and distribution to point of use.

If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 mg/L or chloramine residual of 0.5 mg/L at or near the point of use. Specific attention also must be given to the use of the non-potable water and the management program for the cooling device being supplied. For a typical cooling tower application, the following will be required: 1) biocides to prevent regrowth within the tower; and 2) an overall pathogen program that considers treatment, storage, supply, and use.

Example 3: Analysis of Blackwater Reuse for Toilet Flushing

This example considers the use of a blackwater source that is treated and reused for toilet flushing in a public restroom building. The estimated recycle rate for this system is 90%. For this scenario, refer to the schematic in Figure 9-2.

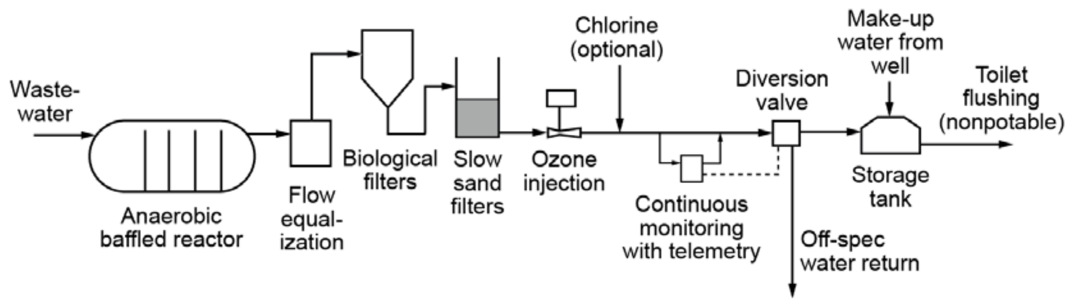

Figure 9-2: Proposed treatment train for a blackwater source used for toilet flushing (Example 3).
Note: this image is duplicated in Figure 4-3 in Chapter 4.

As shown in Figure 9-2, ozone and chlorine are included for disinfection. A continuous monitoring system includes total chlorine, pH, turbidity, color, and oxidation-reduction potential. In a previous *in situ* pilot study, 6-$\log_{10}$ reduction of virus (using MS2 challenge testing) was observed when enough ozone was added to achieve a residual color less than 30 color units in the process effluent (Leverenz, 2016). In the same pilot study, a chlorine dose of 20 mg/L resulted in an effluent total chlorine residual of 5 mg/L at 120-minute contact time, achieving 2-$\log_{10}$ inactivation of bacteria (i.e., indigenous fecal coliform) corresponding to oxidation-reduction potential values ranging from 350 to 450 millivolts.

Step 1. Identify the Management Category and Log_{10} Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, the indoor use of a source water containing human waste in a multi-user building is specified as Management Category 3. The pathogen load from blackwater sources is not significantly different from that found in municipal wastewater. As specified in Table 3-3 in Chapter 3, for toilet flush water, the LRTs are 8.5 for enteric viruses, 7.0 for pathogenic protozoa, and 6.0 for enteric bacteria.

Step 2. Evaluate the Proposed Treatment Process to Achieve the Log_{10} Reduction Targets

The LRVs from Tables 4-1 to 4-5 in Chapter 4 can be used to develop a preliminary assessment of the suitability of the treatment process to meet the LRTs for target pathogen groups. See Table 9-3 for a summary of expected performance.

Table 9-3: Expected Log_{10} Reductions for Select Process Steps for a Blackwater Source Used for Toilet Flushing (Example 3)

Process Step	Expected Log_{10} Reduction		
	Viruses	Protozoa	Bacteria
Anaerobic reactor	0.8	0.5	0.5
Aerobic packed bed filter	1	2	1
Slow sand filtration	2	4	2
Ozonation	>5	0	>4
Combined chlorine	0	0	0
Subtotal	8.8	6.5	>7.5

In this case, the primary disinfection process is ozone, which is ineffective against protozoan pathogens. Based on the computed LRVs, the process (as defined in the problem statement) will not meet the LRT for protozoa.

Using information from Chapter 4, some approaches can be proposed to improve performance with respect to protozoa removal or inactivation. For example, the following supplemental water treatment processes could be used to meet the LRT:

- Cartridge filtration (3 microns; 3-log_{10} reduction protozoa).
- Microfiltration (>4-log_{10} reduction of protozoa).
- UV radiation with a dose of 12 to 13 mJ/cm^2 (~3-log_{10} inactivation of protozoa).

The UV dose specified above is the applied dose, after taking into consideration various uncertainty factors, and usually is applied to large-scale water and wastewater systems where energy savings are relevant. For decentralized systems, a conservative approach using a UV system with a dose of 40 mJ/cm^2 (which accounts for unknowns and uncertainties) is considered adequate for 3-log_{10} inactivation of protozoa. Alternately, *in situ* challenge testing could be used to demonstrate that the process treatment train is capable of achieving the LRTs, and continuous monitoring systems can be used to verify the LRVs.

Notably, because of high ammonium loading in this wastewater, it is difficult to reliably achieve free chlorine. The combined chlorine does not receive log_{10} reduction credit, but rather is included to control the growth of opportunistic pathogens and biofilms in the recycled water distribution system.

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, wastewater for toilet flushing in a multi-user building should have an RME designated as Management Category 3.

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

The proposed system likely would result in a high level of water recycling because most non-potable water is used for toilet and urinal flushing. A high recycle rate (i.e., greater than 50%) would result in increased ionic strength/dissolved solids and increased concentrations of recalcitrant organic constituents that could affect the performance of pathogen control barriers. Without relevant performance data under these conditions, it may be difficult to predict what, if any, impact these constituents could have on the LRVs of individual processes. Consequently, field verification testing will need to take place in two phases: 1) during commissioning after biological processes reach steady-state; and 2) following commissioning after the product/recycled water chemistry reaches steady-state. Some preliminary monitoring plans for the scenario presented in this example are summarized below.

- **Validation testing.** The use of validated technologies or an *in situ* validation study is required for Management Category 3 systems.

- **Field verification.** Challenge testing the PCPs during system commissioning is required for Management Category 3 systems. In general, system commissioning would need about two months for biological processes to stabilize. During the commissioning phase, the system would be operated offline (i.e., the product/recycled water is discharged to an alternative discharge location). Due to the expected high recycle rate for this system, a second field verification test is recommended after the recycled water chemistry reaches steady-state (which is estimated to be one month after the system is placed into service).

  The key PCPs in this example are the ozonation system and UV radiation (assuming UV is added to the treatment train, following ozone, to meet the requirement for protozoa inactivation). Challenge testing should include the use of suitable surrogates for viruses and protozoa. Bacteriophages that should be considered for challenge testing the ozone system include MS2, Fr, and Phi X 174. The UV system could be challenge tested with spores of *B. subtilis*.

- **Continuous verification monitoring.** Continuous monitoring of PCPs is required for Management Category 3 systems. In this case, the PCPs and associated surrogate parameters are presented in Table 9-4.

Other parameters for operational monitoring to consider include pH, temperature, electrical conductivity, flow rate, and others associated with individual process operation. See Table 2-4 in Chapter 2 for a summary of additional recommended design and control features.

Table 9-4: Surrogate Parameters and Control Points for a Blackwater Source Used for Toilet Flushing (Example 3)

Surrogate Parameter	Control Point	Purpose
Total chlorine residual	Near point-of-use	Controls biofouling and the growth of opportunistic pathogens in the distribution system
Continuous turbidity	Slow sand filter effluent	Ensures the integrity of the filtration system
Continuous color, ultraviolet light absorbance (UVA), residual ozone, or oxidation-reduction potential	Ozonated water	Confirms that a sufficient dose of ozone was applied to kill viruses
Continuous ultraviolet (UV) intensity and UVA	UV-treated water	Confirms that a sufficient dose of UV was used to kill protozoa

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For non-potable water systems, consider the chemical characteristics and biological stability of recycled water, as follows:

- In systems with high levels of water recycling, the continuous addition of human wastes will result in an elevated concentration of salts. Care should be taken to identify the acceptable concentration of salts in the recycled water that will not result in corrosion or fouling of the water distribution system. If problems develop related to the concentration of salts, then increase the amount of dilution water and blowdown.

- If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 mg/L or chloramine residual of 0.5 mg/L at or near the point of use.

Example 4: Simple Graywater System for Toilet Flushing

The volume of graywater generated from showers and bathing is approximately equal to the volume of water used for toilet flushing. A graywater system has been proposed in Figure 9-3 for a multi-user building with 100 occupants that will use treated graywater – obtained from showering and handwashing – for toilet flushing.

A study was conducted in advance to collect graywater from a residential building (Ekeren et al., 2016). The graywater was subjected to a bench study to evaluate alternative filtration and disinfection systems. It was found that chlorine (with an initial chlorine dose of 20 mg/L, 60-minute contact time, and 180-mg/L·per minute CT value) and UV (28 mJ/cm^2) was independently able to achieve greater than 6-$\log_{10}$ reduction of *E. coli, S. enterica, and P. aeruginosa*, and about 3-$\log_{10}$ reduction of MS2 coliphage. The average concentration of ammonium in the graywater was about 8 mg/L.

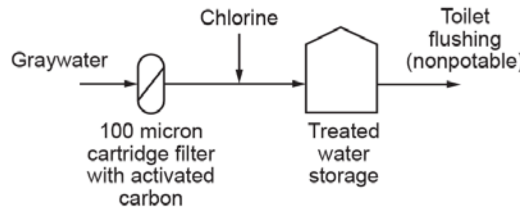

Figure 9-3: Proposed treatment train for a graywater source used for toilet flushing (Example 4).

Step 1. Identify the Management Category and Log_{10} Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, the indoor use of source water containing human waste in a non-single family building is specified as Management Category 3. The LRTs for alternative source waters and non-potable water applications are reported in Table 9-5 (also see Table 3-3 in Chapter 3).

Table 9-5: Summary of Pathogen Log_{10} Reduction Targets for Flushing Toilets with a Graywater Source (Example 4)

Pathogen Group	Log_{10} Reduction Target
Enteric viruses	6.0
Parasitic protozoa	4.5
Enteric bacteria	3.5

Step 2. Evaluate the Proposed Treatment Process to Achieve the Log_{10} Reduction Targets

The typical LRVs from Tables 4-3 through 4-5 in Chapter 4 can be used to develop a preliminary assessment of the suitability of treatment processes to meet the LRTs for target pathogen groups. See Table 9-6 for a summary of expected performance.

Table 9-6: Expected Log_{10} Reductions for Select Process Steps for Flushing Toilets with a Graywater Source (Example 4)

Process Step	Expected Log_{10} Reduction		
	Virus	Protozoa	Bacteria
Cartridge filter	0	0	0
Total chlorine (bench data)	3	Not Measured	6
Total chlorine (**Tables 4.3** to **4.5**)	0	0	0
Subtotal[a]	3	0	6

[a] Based on bench data with a site-specific graywater source.

The bench testing resulted in a higher level of $\log_{10}$ reduction than the expected values listed in Tables 4-3 to 4-5 in Chapter 4. The possible reasons for this discrepancy include: 1) variable ammonium concentration, periodically resulting in some free chlorine formation; 2) a high chlorine dose, resulting in some free chlorine formation; and 3) more effective inactivation of free-swimming challenge test organisms compared to embedded or shielded indigenous organisms. In general, filtration down to 10 microns or less is expected to reduce shielding and produce results consistent with the conditions of the challenge test (i.e., primarily non-embedded pathogens).

In this case, the primary disinfection process is chlorine, which is less effective against protozoan pathogens. Based on the computed LRVs, the process (as defined in the problem statement) will not meet the required LRTs for enteric viruses and pathogenic protozoa. Using information from Chapter 4, some approaches can be proposed to improve performance with respect to virus and protozoa removal or inactivation. The following example modifications could be proposed to meet LRTs:

- Slow sand filtration or cartridge filtration (10 microns or smaller).
- UV disinfection with a dose ranging from 80 to 100 mJ/cm^2.

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, an application with a source water containing human waste, including graywater, and used indoors for toilet flushing in a multi-user building should have an RME designated as Management Category 3.

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

Some preliminary monitoring plans for the scenario presented in Example 4 are summarized as follows:

- **Validation testing.** The use of validated technologies or an *in situ* validation study is required for Management Category 3 systems.

- **Field verification.** Challenge testing the PCPs at system validation is required for Management Category 3 systems. Challenge testing should include the use of suitable surrogates for viruses and protozoa. Coliphages that should be considered for challenge testing the chlorine and UV systems include MS2, Fr, and Phi X 174. Additionally, the UV system could be tested with spores of *B. subtilis*.

- **Operational verification monitoring.** Continuous monitoring of PCPs is required for Management Category 3 systems. The PCPs and associated surrogate parameters are presented in Table 9-7.

Other parameters for operational monitoring to consider include pH, temperature, electrical conductivity, flow rate, and those associated with individual process operation. See Table 2-4 in Chapter 2 for a summary of additional recommended design and control features.

Table 9-7: Surrogate Parameters and Control Points for Flushing Toilets with a Graywater Source (Example 4)

Surrogate Parameter	Surrogate Control Point	Purpose
Total chlorine residual	Near point of use	Controls biofouling and the growth of opportunistic pathogens in the distribution system
Continuous turbidity	Slow sand filter or cartridge filter effluent	Ensures the integrity of filtration system
Residual chlorine or oxidation-reduction potential	Chlorinated water	Confirms that a sufficient dose of chlorine was applied to kill viruses
Continuous ultraviolet (UV) intensity or UV dose and ultraviolet light absorbance (UVA) (if used)	UV-treated water	Confirms that a sufficient dose of UV was used to kill protozoa

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For non-potable water systems, consider the chemical characteristics and biological stability of recycled water, as follows:

- In systems that require the presence of free chlorine to meet the LRTs, the potential for variable ammonium content can be problematic. If possible, identify and control sources of ammonium.
- If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 mg/L or chloramine residual of 0.5 mg/L at or near the point of use. Alternatively, use a heat exchanger to control temperature.

Example 5: Stormwater for Landscape Spray Irrigation

Stormwater is a viable source of water for a community irrigation project. In a previous watershed study, the median concentration of *E. coli* bacteria in stormwater samples was estimated to be 10^4 CFU/100 mL, compared with an *E. coli* concentration of 10^6 CFU/100 mL in typical domestic wastewater (Petterson et al., 2016). The source of *E. coli* has not been determined, but is expected to be principally of animal origin, with minimal sewage ingress, because the wastewater collection infrastructure is new, in good condition, and located within a community with mostly PVC sewer mains. Based on the measurements of *E. coli*, it is estimated that the stormwater could contain up to 1% wastewater (10^{-2}). The following treatment train is proposed in Figure 9-4.

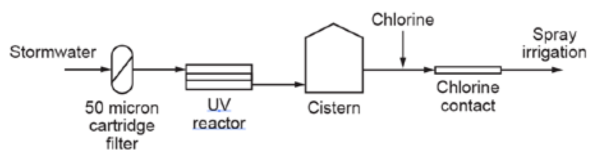

Figure 9-4: Proposed treatment train for stormwater used for spray irrigation (Example 5).

Step 1. Identify the Management Category and $\log_{10}$ Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, spray irrigation of source water containing human waste in areas with public access is specified as Management Category 3. As summarized in Table 9-8, the LRTs (from Table 3-3 in Chapter 3) can be extrapolated assuming stormwater with an average 1% wastewater content.

Table 9-8: Summary of Pathogen $\log_{10}$ Reduction Targets $(LRT)_{95}$ for Spray Irrigation with a Stormwater Source (Example 5)

Pathogen Group	95th Percentile $\log_{10}$ Reduction Targets (LRT_{95}) for Indicated Level of Wastewater Fraction in Stormwater Source		
	Table 3.3		This Project[a]
Enteric viruses	5.0	3.0	4.0
Parasitic protozoa	4.5	2.5	3.5
Enteric bacteria	4.0	2.0	3.0

[a] Interpolated value.

Step 2. Evaluate the Proposed Treatment Process to Achieve the $\log_{10}$ Reduction Targets

The accepted LRVs from different treatment options (see Tables 4-1 to 4-5 in Chapter 4) can be used to select a suitable treatment train to meet the LRTs for each target pathogen group. For the proposed treatment train, a summary of expected performance is given in Table 9-9.

Table 9-9: Expected $\log_{10}$ Reductions for Select Process Steps for Spray Irrigation with a Stormwater Source (Example 5)

Process Step	Expected $\log_{10}$ Reduction		
	Virus	Protozoa	Bacteria
Cartridge filter (50 micron)	0	0	0
UV disinfection (50 mJ/cm^2)[a]	2	4	5
Total chlorine (120 mg•min/L)[b]	<1	0	2
Subtotal[a]	2 – 3	4	7

[a] While the ultraviolet dose is greater than that specified for 4-$\log_{10}$ reduction, the dose table is limited to 4 log. A validation study would be needed to obtain $\log_{10}$ removal values greater than 4.

[b] Assumed to be chloramine.

mJ/cm^2 = Millijoules per square centimeter. mg•min/L = Milligram-minutes per liter.

In this case, the primary disinfection processes are UV and residual total chlorine, the latter known to be less effective against enteric virus pathogens and ineffective against *Cryptosporidium* oocysts. Based on the computed LRVs, the process (as defined in the problem statement) is not expected to meet the LRT for enteric virus if combined chlorine is the primary form of chlorine present. The LRTs for all pathogen groups can be achieved as follows:

- Supplemental cartridge filtration to 10 microns.
- Minimize constituents that react with chlorine and/or add enough chlorine to achieve free chlorine.
- Increase the UV disinfection dose range to between 80 to 100 mJ/cm^2.

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, source waters (including stormwater) containing human waste and used where there is non-negligible exposure should have an RME designated as Management Category 3.

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

Some preliminary monitoring plans for the scenario presented in this example are summarized as follows:

- **Validation Testing.** The use of validated technologies or an *in situ* validation study is required for Management Category 3 systems.

- **Field verification.** Challenge testing the PCPs at system validation is required for Management Category 3 systems. Challenge testing should include the use of suitable surrogates for virus and protozoa. Coliphages that should be considered for challenge testing the chlorine and UV systems include MS2, Fr, and Phi X 174. In addition, the UV system could be tested with spores of *B. subtilis*.

- **Operational verification monitoring.** Continuous monitoring of PCPs is required for Management Category 3 systems. The PCPs and associated surrogate parameters are presented in Table 9-10.

Table 9-10: Surrogate Parameters and Control Points for Spray Irrigation with a Stormwater Source (Example 5)

Surrogate Parameter	Surrogate Control Point	Purpose
Total chlorine residual	Near point of use	Controls biofouling and the growth of opportunistic pathogens in the distribution system
Continuous turbidity	Slow sand filter or cartridge filter effluent	Ensures the integrity of the filtration system
Residual chlorine or oxidation-reduction potential	Chlorinated water	Confirms that a sufficient dose of chlorine was applied to kill viruses
Continuous ultraviolet (UV) intensity or UV dose and ultraviolet light absorbance (UVA) (if used)	UV-treated water	Confirms that a sufficient dose of UV was used to kill protozoa

Other parameters for operational monitoring that should be considered include pH, temperature, electrical conductivity, flow rate, and those associated with individual process operation. See Table 2-4 in Chapter 2 for a summary of additional recommended design and control features.

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For non-potable water systems, consider the chemical characteristics and biological stability of treated stormwater, as follows:

- In systems that require the presence of free chlorine to meet the LRTs, the potential for a variable content of ammonium can be problematic. If possible, identify and control sources of ammonium (e.g., fertilizers and runoff from golf courses and other grassed areas).

- If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 mg/L or chloramine residual of 0.5 mg/L at or near the point of use.

Example 6: Water Reuse for Toilet Flushing, Laundry, and Cooling

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Wastewater collected from toilets, sinks, showers, and laundry, and supplemented by stormwater, is to be treated and used for laundry, toilet flushing, irrigation, cooling tower make-up, and sidewalk maintenance. The overall water recycle rate is expected to be less than 50%; therefore, issues with the accumulation of conserved constituents can be neglected.

As shown in Figure 9-5, the water recycling system consists of a membrane bioreactor followed by a multiple barrier approach for disinfection. The membrane bioreactor is an activated sludge system with membranes that have an effective pore size of 0.07 micron. The disinfection system consists of an ozone generation and contacting system (used for oxidation and color removal), followed by a UV light system for additional disinfection.

Finished water in the storage tank circulates through the ozone and UV systems to maintain the level of disinfection. Automatic potable water fill valves at the water storage tanks ensure an uninterrupted supply of water. In this way, a backup system is available to provide water in the event the recycling system is out-of-service for repair or maintenance. A computerized system automates the control of the process, including calling operators when necessary.

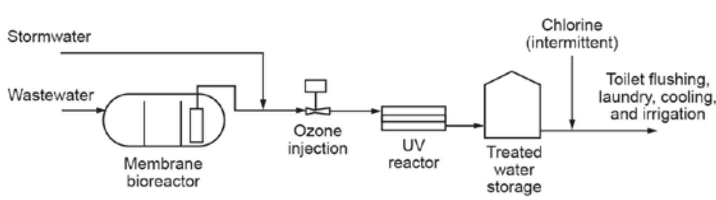

Figure 9-5: Proposed treatment train for a stormwater and wastewater source water used for toilet flushing, laundry, cooling, and spray irrigation (Example 6).

Step 1. Identify the Management Category and Log_{10} Reduction Targets for the Reference Pathogen Groups

Based on Figure 2-1 in Chapter 2, the indoor use of source water containing human waste in a multi-user building is specified as Management Category 3. The LRTs for alternative source waters and non-potable applications are reported in Table 3-3 in Chapter 3.

The pathogen load from blackwater sources does not differ significantly from that found in domestic wastewater. As specified in Table 3-3 for wastewater used for indoor reuse, the LRTs are 8.5 for enteric viruses, 7.0 for pathogenic protozoa, and 6.0 for enteric bacteria. The stormwater has assumed LRTs of 3.0 for virus, 2.5 for protozoa, and 2.0 for bacteria. For the blended stream, the LRTs for wastewater will control the analysis. As summarized in Table 9-11, enteric bacteria are the primary pathogen group.

Table 9-11: Summary of Pathogen Log_{10} Reduction Targets for the Indoor Use of a Source Water Derived from Blending Wastewater and Stormwater (Example 6)

Pathogen Group	Log_{10} Reduction Target
Enteric viruses	8.5
Parasitic protozoa	7.0
Enteric bacteria	6.0

Step 2. Evaluate the Proposed Treatment Process to Achieve the Log_{10} Reduction Targets

The typical LRVs from Tables 4-1 to 4-5 in Chapter 4 can be used to develop a preliminary assessment of the suitability of treatment processes to meet the LRTs for target pathogen groups. A summary of expected performance based on Tables 4-1 to 4-5 and for this specific example is given in Table 9-12.

Table 9-12: Expected Log_{10} Reductions for Select Process Steps for the Indoor Use of a Source Water Derived from Blending Wastewater and Stormwater (Example 6)

Process Step	Expected Log_{10} Reduction		
	Viruses	Protozoa	Bacteria
Suspended growth bioreactor	0.5	0.5	1
Microfilter[a]	1	>6	>6
Ozonation (0.5 mg•min/L)	4	0	>4
Ultraviolet disinfection (40 mJ/cm^2)	0.5	4	3
Subtotal	6.0	>10	>14

[a] These log_{10} reductions are appropriate only if the membrane remains in the same condition of integrity as when the unit was validated. Membrane integrity testing is recommended.

mg•min/L = Milligram-minutes per liter. mJ/cm^2 = Millijoules per square centimeter.

In this case, the primary disinfection processes are ozone and UV (which, when combined, are effective against most known pathogens). Based on the computed LRVs, the process (as defined in the problem statement) will not meet the LRT for enteric viruses. UV dosage can be increased to150 mJ/cm^2 to achieve 3-log$_{10}$ inactivation of enteric viruses.

Field verification of the LRT at commissioning is recommended to demonstrate that the process treatment train is capable of achieving the LRTs. Continuous monitoring systems can be used to verify the LRVs.

Step 3. Designate the Management Category of the Responsible Management Entity

As discussed in Chapter 5, wastewater for toilet flushing in a multi-user building should have an RME designated as Management Category 3.

Step 4. Develop a Monitoring Plan for the Proposed Non-Potable Use

The monitoring plan will depend on the type of treatment technologies used, designated Management Category of the RME, and system-specific considerations. Some preliminary monitoring plans for the scenario presented in this example are summarized as follows:

- **Validation testing.** The use of validated technologies is required for Management Category 3 systems. Many UV reactors are validated using water quality with low UVA (i.e., high transmittance). Because blackwater and graywater may have lower transmittance, validation testing or field verification must account for the increased UVA. In this case, the multiple barrier system already was validated through *in situ* testing at other sites, which meets requirements for validation testing.

- **Field verification.** A performance check at the PCPs during commissioning is required for Management Category 3 systems. Challenge testing should include the use of suitable surrogates for viruses and protozoa. Coliphages that should be considered for challenge testing the ozone and UV systems include MS2, Fr, and Phi X 174. In addition, the UV system could be tested with the spores of *B. subtilis*.

- **Continuous verification monitoring.** Continuous monitoring of PCPs is required for Management Category 3 systems. The PCPs and associated surrogate parameters are presented in Table 9-13.

The set point for UV intensity will differ depending on the validation of the UV reactor equipment. Most UV systems are set for water quality assuming low UVA (i.e., high transmittance); therefore, the UV intensity set point should be confirmed during field verification. Turbidity is considered a gross indicator of membrane performance, and pressure decay testing is the standard used to evaluate membrane integrity. Other parameters for operational monitoring to consider include pH, temperature, electrical conductivity, flow rate, and those associated with operating individual processes. See Table 2-4 in Chapter 2 for additional recommended design and control features.

Table 9-13: Surrogate Parameters and Control Points for the Indoor Use of a Source Water Derived from Blending Wastewater and Stormwater (Example 6)

Surrogate Parameter	Control Point	Purpose
Total chlorine residual	Near point of use	Controls biofouling and the growth of opportunistic pathogens in the distribution system
Continuous turbidity, membrane integrity testing/ pressure decay testing	Microfilter effluent	Ensures the integrity of the filtration system
Continuous color, ultraviolet light absorbance (UVA,) residual ozone, or oxidation-reduction potential	Ozonated water	Confirms that a sufficient dose of ozone was applied to kill viruses
Continuous ultraviolet (UV) intensity	UV-treated water	Confirms that a sufficient dose of UV dose was used to kill protozoa

Step 5. Develop Best Management Practices for the Proposed Non-Potable Use

For non-potable water systems, consider the chemical characteristics and biological stability of recycled water, as follows:

- In systems with high levels of water recycling, the continuous addition of human wastes can result in elevated concentrations of salts. Care should be taken to identify the acceptable concentration of salts in the recycled water to avoid corrosion or fouling in the water distribution system. If problems develop related to the concentration of salts, then increase the amount of dilution water and blowdown.

- If the temperature of water in the non-potable water distribution system exceeds 25°C (which is a condition that could promote the growth of opportunistic pathogens like *Legionella)*, then maintain a free chlorine residual of 0.2 mg/L or monochloramine residual 0.5 mg/L at or near the point of use.

CHAPTER 10

Future Needs

The Panel developed this framework to provide guidance to develop DNW systems that are reliable, efficient, affordable, and protect public health. During the development of this framework, the Panel and Stakeholder Advisory Committee identified several future research needs to improve this approach. Notably, this framework is flexible and should be adapted as research needs evolve. The research needs identified in this chapter are not exhaustive. Rather, they represent those most important to the stakeholders and Panel members involved in this project.

10.1 Research Needs to Support Quantitative Microbial Risk Assessment

Data to support QMRA for roof runoff and stormwater were limited at the time this report was published. Although stormwater pathogen concentrations for a particular system can be addressed through more sampling (as enteric pathogens and sewage markers are prevalent), determining roof runoff pathogen concentrations is more problematic.

Characteristics of the ideal dataset for conducting QMRA from OBSERVATIONS OF PATHOGEN CONCENTRATIONS IN ROOF RUNOFF

- Fresh rainwater is sampled before it enters storage.
- Pathogens are monitored using culture methods and qPCR.
- Results are targeted to human infectious strains/groups.
- The limit of detection is expressed as a concentration for each pathogen and method.
- Samples are collected across various locations and over time to properly characterize the spatial and temporal occurrence of potential pathogens in collected rainwater.
- Data is collected for different climatic and geographic conditions in North America.

Characteristics of an ideal dataset for conducting QMRA using the ANIMAL FECAL APPROACH

- The same fecal indicators are monitored in roof runoff and fresh individual feces, ideally collected before entering storage and after a storage period consistent with operational storage time.
- Reference pathogens and their surrogates have similar fate and transport.
- Pathogens are monitored using culture/direct detects and qPCR.
- qPCR results are targeted to human infectious strains/groups.
- The recovery and limit of detection are expressed as a concentration for each pathogen and method.

For the major reference pathogens, improved exposure models are needed to address non-potable water uses. For example:

- The volume of water ingested/inhaled during toilet flushing (both from aerosols and contact exposures) or by clothes washing machines (particularly, the top-loading variety) and rinse cycles without detergent/bleach.

- The frequency of accidental ingestion and cross-connection events, which may be more critical in determining the overall risk.

Of particular importance is to use recent developments in estimating Norovirus infectivity (e.g., with aged stormwater and efficacy of treatment/disinfectants) and the importance (or not) of virion aggregation. There also is a need to have access to dose-response relationships for different user-classes (e.g., children and the elderly) and for low-dose exposures that currently are assumed to be linear.

10.2 Research Needs to Support *In Situ* Log_{10} Reduction Performance

Endogenous surrogates should be identified for each class of pathogens (i.e., viral, bacterial, and protozoan). The use of surrogates could eliminate the need for external spiking/challenges to undertake challenge testing. Furthermore, given the rapid advances in genomics and sensors, surrogates could be used for continuous or semi-continuous monitoring. Current studies that use metagenomic analyses are revealing various classes of microorganisms at much greater concentrations and consistencies in various wastewater streams than previously thought; these metagenomic tools could be used to identify potential targets.

10.3 Risk Models on Small Systems

The intent of this framework is to address public health issues related to systems at the multi-user building scale (i.e., any building that is not a single residence). This class of buildings includes multi-residential apartment, commercial, mixed use, and other structures. Consequently, the risk models used to provide the recommended LRTs are based on systems that pose a higher likelihood of exposure to a community. The risk models must be refined to correlate the specific number of exposures in population equivalents per day with targeted public health goals, which would allow small systems with low usage to be assessed from a public health perspective and would allow the establishment and correlation of population equivalents per day of exposure with the appropriate Management Category. From the perspective of establishing clear guidelines for management oversight, the performance of small systems must be controlled adequately, but not be over-regulated.

10.4 Expanding the Framework to Other Water Sources and Uses

The Panel did not address all water sources and end uses in this framework. Rather, the focus is on common sources and end-uses where sufficient data are available to support QMRA and recommendations for LRTs. Source waters addressed include blackwater, graywater, domestic wastewater, roof runoff, and stormwater (which, due to lack of specific pathogen data, includes foundation water). The Panel only considered non-potable end uses (i.e., toilet flushing, clothes washing, unrestricted access irrigation cooling and dust suppression, and cooling towers).
Other possible uses of non-potable water produced by these systems include fountains and sprinklers for fire suppression. These uses require additional assessment of water-based opportunistic pathogen growth (discussed in Section 10.5), which is assumed to depend upon water temperature, organic load/biofilm development, disinfectant residual concentration, and the rates of aerosolization and factors influencing aerosol transport to recipients. One specific area requiring further research is evaporator make-up water for schools, hospitals, and other environments with high "at-risk" populations.

On the decentralized scale, one practice gaining interest is the use of urine diversion toilets, which separately collect urine for intended beneficial uses (e.g., fertilizer). The Panel did not address this practice due to the need for additional research on the possible risks associated with the use of diverted "yellow water" and its storage prior to use as fertilizer.

10.5 Opportunistic Pathogens

The potential exists for opportunistic pathogens to grow in distribution systems that supply potable or non-potable water. Further investigation is needed regarding the potential for the growth of these organisms in non-potable distribution systems. While non-potable water sources are more likely to contain nutrients that support the growth of microorganisms, these waters usually are not heated for use in residences (e.g., toilet flushing and irrigation). More data are needed on the densities of opportunistic pathogens that may grow in recovered waters, particularly post-treatment, and can impact human health through inhalation (e.g., *Legionella*, non-tuberculous mycobacteria) and transmission through skin (e.g., non-tuberculous mycobacteria and *Pseudomonas aeruginosa*). Such research could support recommendations on control strategies for opportunistic pathogens in the context of system growth niches.

10.6 New Monitoring Approaches

The rapidly evolving fields of genomics and sensors have the potential to enhance monitoring systems, including: 1) defining endogenous biological organisms used to verify $\log_{10}$ reduction, thereby eliminating the need to spike large numbers of surrogate organisms; and 2) supporting the creation of new online sensors for continuous monitoring.

10.7 Appropriate Surrogates and Monitoring Systems

Data are available to justify the use of indigenous bacteria in wastewater at sufficiently high levels to verify LRTs; however, more work is needed with biological and non-biological surrogates for viruses and parasites to determine their applicability for verification of the LRTs achieved. The rapidly developing fields of genomics and microbiomes are relevant and applicable towards continuous sensor technology and advanced monitoring strategies.

10.8 Compiling Past and Future Performance Data and Validation Study Reports

Literature review is needed of the expected $\log_{10}$ reduction performance for various unit processes and how *in situ* validation may be undertaken to better describe "as built" performance variability. Such an effort is currently being undertaken in Australia for large-scale systems (Muston and Halliwell, 2011). More research also is needed on the suitability of Bayes networks to analyze the LRV performance of unit processes (Roser et al., 2014).

Although data exist on the performance of unit processes, a single data repository does not exist. Performance data for existing systems either have not been collected or are not publicly available. Similarly, the test reports for technology validation often are prepared to gain approval from regulatory agencies, but these reports are not readily available in a central location.

In general, a database of performance and validation test data from existing treatment processes (including details on source water, O&M, and other relevant operational parameters) would be useful to engineers and regulators during the development and permitting of effective and reliable treatment trains. In addition, a database would be invaluable for researchers seeking to identify data gaps that exist for new technologies and alternative disinfectants. Such a database could be web-based, with a standard interface for users to input performance data and upload validation study reports. A manager would ensure the quality and integrity of the data and reports and facilitate data submittals.

10.9 Compiling Legal Forms of Asset Ownership and Financial Security

Each state has its own specific rules regarding the legal forms of water and wastewater infrastructure ownership. These rules may prohibit or complicate the ability to deploy a DNW system, and the review and compilation of those rules would provide important information regarding feasible asset ownership options for DNW systems. In addition, each state has rules regarding the legal forms of financial security allowed for water and wastewater infrastructure, as well as for rating and controlling the financial institutions that provide such security. These rules and ratings influence the mechanisms by which an RME may establish financial security for the DNW system. Compiling and summarizing the pertinent rules and legislation in each state for asset ownership and financial security would be valuable to regulators and prospective developers of DNW systems. This compilation would allow each state to benefit from the experiences of others.

10.10 Decision Support Tools

Public understanding of how the RME options fit within their communities requires educating local stakeholders and aligning the project with community values and expectations. Decision support tools are needed that address both the allocation of risk and the assessment of the sustainability of DNW systems. Communities and developers often are interested in installing DNW systems to achieve sustainability and green building goals. The advantages and challenges associated with DNW systems, however, need better quantification to properly inform decisions regarding whether these projects should be implemented and what source waters and end-uses should be considered. Decision support tools should provide information on the following:

- Life cycle of the project, including energy and greenhouse gas emissions.
- Impact to the reliability and resiliency of water supplies.
- Risks at multiple scales and in relation to source waters and end uses.

A decision support tool also is necessary to establish a mechanism for engaging the community and efficiently reaching agreement as to what regulations to implement, who will serve as the regulatory authority, and how to fund the system. The U.S. EPA and Water Environment and Reuse Foundation have done much work relative to the RME issue regarding onsite wastewater systems. This work should be updated to reflect the current mechanisms available today and the specific characteristics of DNW systems.

10.11 Development of a Program for the Third-Party Review of Decentralized Non-Potable Water Systems

Training programs could be developed in which third-party professionals receive registration or certification to review and/or certify PARs for DNW systems. The design, review, and approval of best management practices for stormwater could be used as a model. For example, the California Stormwater Quality Association (CASQA) has a program for individuals to become a Qualified Stormwater Pollution Prevention Plan (SWPPP) Practitioner (QSP) and/or Qualified SWPPP Developer (QSD). Information on the qualification program is available online at the CASQA website at https://www.casqa.org/resources/qsp-qsd-qualification.

STEPS TO ACHIEVE CERTIFICATION FOR THIRD-PARTY REVIEW

1. Enroll in a training course.
2. Register to take a certification exam.
3. Provide proof of prerequisite professional certifications/registrations (e.g., Registered Professional Civil or Environmental Engineer, Registered Landscape Architect).
4. Take and pass a certification exam.

A similar program could be developed to provide certification for DNW system professionals. Prerequisite professional certifications could include Registered Professional Engineer, Registered Onsite Wastewater Professional, or Certified Plumber. Such a program would provide trained professionals with specific knowledge of DNW systems, creating a resource for health departments lacking in-house expertise to review PARs and approve proposed projects.

Building a community of professionals trained and accustomed to reviewing DNW systems could streamline the process for installing these systems and provide confidence that these systems meet public health goals.

References

Adelman, M.J.; Phelps, M.; Hadacek, R.T.; Slosser, O.R.; Calvet, S.; Oppenheimer, J.; Borchardt, J.H. Required C x T Value for 5-log Virus Inactivation at Full Scale. *Journal of the American Water Works Association (Journal AWWA)*, 2016, *108(1)* E18-E26.

ANSI/ASHRAE Standard 188-2015.Legionellosis: Risk Management for Building Water Systems. Atlanta, GA. American National Standards Institute (ANSI)/ASHRAE Standard 188-2015, 2015. www.ashrae.org/resources--publications/bookstore/ansi-ashrae-standard-188-2015-legionellosis-risk-management-for-building-water-systems (accessed Nov 21, 2016).

Asano, T.; Burton, F.L.; Leverenz, H.; Tsuchihashi, R.; Tchobanoglous, G. *Water Reuse: Issues, Technologies, and Application,* 1st ed., McGraw-Hill: New York, 2007.

Ashbolt, N.J. Environmental (Saprozoic) Pathogens of Engineered Water Systems: Understanding Their Ecology for Risk Assessment and Management. *Pathogens,* 2015, *4(2),* 390-405.

Ashbolt, N.J. University of Alberta, Edmonton, Canada. Personal communication, 2016.

AWRCE. *WaterVal – Streamlining Technology Vertification: Protocol Template;* Australian Water Recycling Centre of Excellence: Brisbane, Queensland, Australia, 2009.

Beer, K.D.; Gargano, J.W.; Roberts, V.A.; Hill, V.R.; Garrison, L.W.; Kutty, P.K.Hilborn, E.D.; Wade, T.J.; Fullerton, K.E.; Yoder, J.S. Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water - United States, 2011-2012. *MMWR Morb Mortal Wkly Rep.* 2015, *64(31),* 842-848.

Besner, M.C.; Ebacher, G.; M. Prévost, M. Public Health Risk of Microbial Intrusion Events in Distribution Systems. In *Water Contamination Emergencies: Managing the Threats*; Borchers, U.; Gray, J.; Thompson. K.C.; Eds.; The Royal Society of Chemistry: London, England, 2013; pp 145-155.

Boczek, L.A., E.R. Rhodes, J.L. Cashdollar, J. Ryu, J. Popovici, J.M. Hoelle, M. Sivaganesan, S.L. Hayes, M.R. Rodgers, and H. Ryu (2016). "Applicability of UV resistant Bacillus pumilus endospores as a human adenovirus surrogate for evaluating the effectiveness of virus inactivation in low-pressure UV treatment systems." *J. Micro. Meth*., 122: 43–49.

Bounty, S.; Rodriguez, R.A.; Linden, K.G. Inactivation of Adenovirus Using Low-Dose UV/H2O2 Advanced Oxidation. *Water Research,* 2012, *46(19),* 6273-6278.

California Debt and Investment Advisory Commission. *An Overview of Local Government General Obligations Bond Issuance Trends, 1985-2005;* CDIAC# 08-03; California Debt and Investment Advisory Commission (CDIAC): Sacramento, CA, 2008.

Center for California Homeowner Association Law. Law and Legislation. www.calhomelaw.org/doc.asp?id=460 (accessed Nov 8, 2016).

Cervero-Aragó, S.; Rodriguez-Martínez, S.; Puertas-Bennasar, A.; Araujo, R.M. Effect of Common Drinking Water Disinfectants, Chlorine and Heat on Free *Legionella* and amoebae-associated *Legionella*. *PLoS One* 2015, *10*(8), e0134726.

Chapman, H.; Cartwright, T.; Huston, R.; O'Toole, J. *Water Quality and Health Risks from Urban Rainwater Tanks*. Research Report No 42; CRC for Water Qaulity and Treatment: Salisbury, Australia, 2008.

Chong, M.N.; Sidhu, J.; Aryal, R.; Tang, J.; Gernjak, W.; Escher, B.; Toze, S. Urban Stormwater Harvesting and Reuse: A Probe into the Chemical, Toxicology and Microbiological Contaminants in Water Quality. *Environmental Monitoring and Assessment* 2013, *185(8),* 6645-6652.

Collier, S.A.; Stockman, L.J.; Hicks, L.A.; Garrison, L.E.; Zhou, F.J.; Beach, M.J. Direct Healthcare Costs of Selected Diseases Primarily or Partially Transmitted by Water. *Epidemiol Infection* 2012, *140(11),* 2003-2013.

Crites, R.; Tchobanoglous, G. *Small and Decentralized Wastewater Management Systems*, 1st ed.; McGraw-Hill, Boston, MA, 1998.

Ekeren, K.M.; Hodgson, B.A.; Sharvelle, S.E.; De Long, S.K. (2016) Investigation of Pathogen Disinfection and Regrowth in a Simple Graywater Recycling System for Toilet Flushing. *Desalination and Water Treatment* 2016, 57(54).

EPRI. *Sustainable Water Resources Management, Volume 3: Case Studies on New Water Paradigm*; Report Number 1020587; Electric Power Research Institute (EPRI) and Tetra Tech: Palo Alto, CA, 2010.

Epstein, K. NYC's Living Lesson. *High Performing Buildings Magazine of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)*, 2008.

Fewtrell, L.; Bartram, J.; Eds. *Water Quality: Guidelines, Standards and Health. Risk Assessment and Management for Water Related Infectious Diseases*, World Health Organization (WHO); IWA Publishing; London, England, 2001. www.who.int/water_sanitation_health/publications/whoiwa/en/ (accessed Nov 17, 2016).

Haas, C.H., Rose; J.B.; Gerba, C.P. *Quantitative Microbial Risk Assessment*, 1st ed.; John Wiley and Sons: New York, NY, 1999.

Harrington, G.W.; Chen, H.W.; Harris, A.J.; Xagoraraki, I. *Removal of Emerging Waterborne Pathogens;* AWWA Research Foundation and the American Water Works Association: Denver, CO, 2001.

Health and Safety Executive. *Legionnaires' Disease: Control of Legionella Bacteria in Water Systems,* L8 4th ed*.;* Health and Safety Executive, London, England, 2013a.

Health and Safety Executive. *Legionnaires' Disease: Technical Guidance Part 1: The Control of Legionella Bacteria in Evaporative Cooling Systems;* Health and Safety Executive: London, England, 2013b.

Health and Safety Executive. *Legionnaires' Disease: Technical Guidance Part 3: The Control of* Legionella *Bacteria in Other Risk Systems*; Health and Safety Executive: London, England, 2013c.

Health and Safety Executive. *The Control of Legionella Bacteria in Water Systems. Approved Code of Practice and Guidance*, Health and Safety Executive: London, England, 2013d.

Health and Safety Executive. *Legionnaires' Disease: Technical Guidance Part 2: The Control of* Legionella *Bacteria in Hot and Cold Water Systems;* HSG274 Part 2; Health and Safety Executive: London, England, 2014.

International Association of Plumbing and Mechanical Officers (2015). *Uniform Plumbing Code*. http://codes.iapmo.org/home.aspx?code=UPC (web page accessed 2/22/2017).

Jahne, M., Schoen, M.; Ashbolt, N.; Garland, J. Simulated Enteric Pathogen Concentrations in Locally-Collected Graywater and Wastewater for Microbial Risk Assessments. *Microbial Risk Analysis,* in press 2016.

Jjemba, P.; Johnson, W.; Bukhair, Z.; LeChevallier, M. *Develop Best Management Practices to Control Potential Health Risks and Aesthetic Issues Associated with Reclaimed Water Storage and Distribution*; Project No. 11-03; WateReuse Research Foundation (WRRF): Alexandria, VA, 2015.

Johnson Foundation at Wingspread. *Optimizing the Structure and Scale of Urban Water Infrastructure: Integrating Distributed Systems*; The Johnson Foundation at Wingspread; Racine, WI: 2014. www.johnsonfdn.org/sites/default/files/reports_publications/CNW-DistributedSystems.pdf (accessed Nov 17, 2016).

Khan, S.J.; McDonald, J.A. Quantifying Human Exposure to Contaminants for Multiple-Barrier Water Reuse Systems. *Water Science Technology*, 2010, *61(1),* 77-83.

LeChevallier, M.W.; Lowry, C.D.; Lee, R.G. Disinfection Biofilms in a Model Distribution System. *Journal of the American Water Works Association (Journal AWWA)*, 1990, *82(7);* 87.

LeChevallier, M.W. Conditions Favouring Coliform and HPC Bacterial Growth in Drinking Water and on Water Contact Surfaces. In *Heterotrophic Plate Counts and Drinking-water Safety: The Significance of HPCs for Water Quality and Human Health;* Bartram, J., Cotruvo, J., Exner, M., Fricker, C., Glasmacher, A., Eds; World Health Organization (WHO); IWA Publishing: London, UK, 2003, pp 177-198.

Leverenz, H.L. (2016). *Evaluation of Surrogate Parameters for Disinfection Performance in Onsite Water Reuse.* Dept of Civil and Environmental Engineering, University of California, Davis. Unpublished.

Linden, K., Salveson, A.T.; Thurston, J. *Study of Innovative Treatments for Reclaimed Water;* Project No. 02-09; WateReuse Research Foundation (WRRF): Alexandria, VA, 2012.

Los Angeles County Department of Public Health. Guidelines for Alternate Water Sources: Indoor and Outdoor Non-potable Uses. Los Angeles County Department of Public Health; Los Angeles, CA: 2016. http://publichealth.lacounty.gov/eh/docs/ep_cross_con_AltWaterSourcesGuideline.pdf (accessed Nov 17, 2016).

Maimon, A., Tal, A.; Friedler, E.; Gross, A. Safe On-site Reuse of Greywater for Irrigation – A Critical Review of Current Guidelines. *Environmental Science and Technology* 2010, *44,* 3213-3220.

Mara, D.; Horan, N., Eds. *The Handbook of Water and Wastewater Microbiology*. Academic Press: London, U.K., 2003.

Marchesi, I.; Ferranti, G.; Bargellini, A.; Marchegiano, P.; Predieri, G.; Stout, J. E.; Borella, P. Monochloramine and chlorine dioxide for controlling *Legionella pneumophila* contamination: biocide levels and disinfection by-product formation in hospital water networks. *J Wat Health* **2013,** *11*(4): 738-747.

Murray, C.J.; Acharya, A.K. Understanding DALYs (Disability-Adjusted Life Years). *Journal of Health Economics* 1997, *16(6),* 703-730.

Muston, M.; Halliwell, D. *NatVal Road Map Report: The Road Map to a National Validation Framework for Water Recycling Schemes*; Australian Water Recycling Centre of Excellence, WQRA Project No. 3009-10; Water Quality Research Australia: Adelaide, Australia, 2011, p 65.

NRC. *Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits*. National Research Council, National Academies Press: Washington, DC, 2016.

NRMMC; EPHC; AHMC. *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) - November 2006*. Document No. 21 National Water Quality Management Strategy; Natural Resource Management Ministerial Council (NRMMC), Environment Protection (EPHC),Australian Health Ministers Conference (AHMC); Biotext Pty Ltd., Canberra: Australia, 2006.

NRMMC; EPHC; NHMRC. *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) 22 Augmentation of Drinking Water Supplies - May 2008;* Document No. 22 National Water Quality Management Strategy; Natural Resource Management Ministerial Council (NRMMC), Environment Protection and Heritage Council (EHPC), National Health and Medical Research Council (NHMRC); Biotext Pty Ltd, Canberra: Australia, 2008.

NRMMC; EPHC; NHMRC. *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse - July 2009*; Document No. 23 National Water Quality Management Strategy; Natural Resource Management Ministerial Council (NRMMC), Environment Protection and Heritage Council (EHPC), National Health and Medical Research Council (NHMRC); Biotext Pty Ltd, Canberra: Australia, 2009.

NSF (2016). *NSF/ANSI 350 and 350-1: Onsite Water Reuse.* Webpage of the National Sanitation Foundation.

www.nsf.org/services/by-industry/water-wastewater/onsite-wastewater/onsite-reuse-water-treatment-systems (accessed Dec 2, 2016).

Nshimyimana, J.P.; Ekklesia, E.; Shanahan, P.; Chua, L.H.; Thompson, J.R. Distribution and Abundance of Human-Specific *Bacteroides* and Relation to Traditional Indicators in an Urban Tropical Catchment. *Journal of Applied Microbiology* 2014, *116(5),* 1369-1383.

NWRI. U*ltraviolet Disinfection – Guidelines for Drinking Water and Water Reuse,* 3rd ed.; Publication No. NWRI-2012-04; National Water Research Institute (NWRI): Fountain Valley, CA in collaboration with Water Research Foundation (WRF): Denver, CO, 2012.

Olivieri, A.; Eisenberg, D.; Soller, J.; Eisenberg, J.; Cooper, R.; Tchobanoglous, G.; Trussell, R.; Gagliardo, P. Estimation of Pathogen Removal in an Advanced Water Treatment Facility Using Monte Carlo Simulation. *Water Science and Technology* 1999, *40(4-5),* 223-234.

Petterson, S. R., Mitchell, V.G.; Davies, C.M.; O'Connor, J.; Kaucner, C.; Roser, D.; Ashbolt , N. Evaluation of Three Full-Scale Stormwater Treatment Systems with Respect to Water Yield, Pathogen Removal Efficacy and Human Health Risk from Fecal Pathogens. *Science of the Total Environment* 2016, *543, (Pt A),* 691-702.

Petterson, S.; Ashbolt. N.J. QMRA and Water Safety Management: Review of Application in Drinking Water Systems. *Journal of Water and Health* 2016, *14(4)*, 571-589.

Roser, D.; Ortega, G.C.; Lins, V.; Khan, S. *National Validation Guidelines for Water Recycling; Subproject 4 Comprehensive Validation Strategies for Water Recycling Systems Support Document: A Bayes Net Primer for Water Reuse* (Draft v 1.0). Australian Water Recycling Center of Excellence: Brisbane, QLD, Australia, 2014, p 52.

Schoen, M. E.; Ashbolt, N.J. Assessing Pathogen Risk to Swimmers at Non-Sewage Impacted Recreational Beaches. *Environmental Science and Technology,* 2010, *44*(7), 2286-2291

Schoen, M.E.; Garland, J. Review of Pathogen Treatment Reductions for Onsite Non-Potable Reuse of Alternative Source Waters. Microbial Risk Analysis [Online] 2015, http://dx.doi.org/10.1016/j.mran.2015.10.001 (accessed Nov 22, 2016).

Schoen, M.E.; Ashbolt, N.J.; Jahne, M.A.; Garland, J. Risk-Based Enteric Pathogen Reduction Targets for Non-Potable and Direct Potable Use of Roof Runoff, Stormwater, Greywater, and Wastewater. Microbial Risk Analysis [Online] 2017, *http://dx.doi.org/10.1016/j.mran.2017.01.002* (accessed March 3, 2017).

SFPUC *San Francisco's Non-potable Water Program: A Guidebook for Implementing Onsite Water Systems in the City and County of San Francisco.* San Francisco Public Utilities Commission (SFPUC), San Francisco Department of Building Inspection, San Francisco Department of Public Health: San Francisco, CA, 2015. www.sfwater.org/modules/showdocument.aspx?documentid=4962 (accessed Nov 22, 2016).

SFPUC. *San Francisco's Non-potable Water System Projects.* San Francisco Public Utilities Commission (SFPUC): San Francisco, CA, 2016. www.sfwater.org/Modules/ShowDocument.aspx?documentID=7089 (accessed Nov 22, 2016).

Sinclair, M.; Roddick, F.; Grist, S.; Nguyen, T; O'Toole, J.; Leder, K. Variability in 24 Hour Excretion of Cyanuric Acid: Implications for Water Exposure Assessment. *Journal of Water and Health* 2016a, *14(2),* 192-198.

Sinclair, M., Roddick, F.; Nguyen, T.; Jones, O.; O'Toole, J.; Wolfe, R.; Leder, K. *The Car Wash Pilot Study: Simulating Potential Recycled Water Ingestion;* Research Project 3021. Water Research Australia Limited (WaterRA): Adelaide, SA, 2016b.

Smeets, P.W.M.H.; Rietveld, L.C.; van Dijk, J.C.; Medema, G.J. Practical Applications of Quantitative Microbial Risk Assessment (QMRA) for Water Safety Plans. *Water Science and Technology* 2010, *61(6),* 1561-1568.

Sobsey, M.D. Inactivation of Health Related Microorganisms in Water by Disinfection Processes. *Water Science and Technology* 1989, *21(3),* 179-195.

State of Victoria. *Guidelines for Validating Treatment Processes for Pathogen Reduction: Supporting Class A Recycled Water Schemes in Victoria - February 2013*. Department of Health: Australia, 2013.

Sun, P.; Tyree, C.; Huang, C.H. Inactivation of Escherichia Coli, Bacteriophage MS2, and Bacillus Spores under UV/H2O2 and UV/Peroxydisulfate Advanced Disinfection Conditions. *Environmental Science & Technology* 2016, *50,* 4448−4458.

Tchobanoglous, G.; J. Cotruvo, J.; Crook, J.; McDonald, E.; Olivieri, A.; Salveson, A.; Trussell, R.S. *Framework for Direct Potable Reuse*; Project No. 14-20; WateReuse Association (WRA): Alexandria, VA, 2015.

Tchobanoglous, G.; Stensel, H.D.; Tsuchihashi, R.; Burton, F.L. *Wastewater Engineering: Treatment and Resource Recovery*, 5th ed. Metcalf & Eddy/AECOM, McGraw-Hill: New York, NY, 2014.

Teunis P. F. M. and A. H. Havelaar. (2000). The Beta Poisson Dose-Response Model Is Not a Single-Hit Model. Risk Analysis, 20(4): 513–520

Teunis, P.F., Rutjes, S.A.; Westrell, T.; de Roda Husman, A.M. Characterization of Drinking Water Treatment for virus Risk Assessment. *Water Resources* 2009, *43(2),* 395–404.

U.S. EPA. *Case Studies of Individual and Clustered (Decentralized) Wastewater Management Programs – State and Community Management Approaches 2012.* United States Environmental Protection Agency (U.S. EPA) Office of Wastewater Management: Washington, DC, 2012a. www2.epa.gov/sites/production/files/2015-06/documents/decentralized-case-studies-2012.pdf (accessed Nov 22, 2016).

U.S. EPA. *Membrane Filtration Guidance Manual;* EPA 815-R-06-009; United States Environmental Protection Agency (U.S. EPA) Office of Water: Cincinnati, OH, 2005.

U.S. EPA. *Recreational Water Quality Criteria;* EPA 820-F-12-058; United States Environmental Protection Agency (U.S. EPA) Office of Water: Washington, DC, 2012b.

U.S. EPA. *Title 40: Protection of Environment, Part 141-National Primary Drinking Water Regulations, Subpart I-Control of Lead and Copper.* Electronic Code of Federal Regulations (e-CFR) United States Environmental Protection Agency (U.S. EPA) U.S. Government Publishing Office: Washington, DC, 1991. www.ecfr.gov/cgi-bin/text-idx?SID=531617f923c3de2cbf5d12ae4663f56d&mc=true&node=sp40.23.141.i&rgn=div6

U.S. EPA. *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule;* EPA 815-R-06-007, United States Environmental Protection Agency (U.S. EPA), Office of Water: Cincinnati, OH, 2006.

WERF. *Responsible Management Entities Guidance Fact Sheets.* Water Environment Research Foundation (WERF): Alexandria, VA, 2009. www.werf.org/rme/i/c/KnowledgeAreas/DecentralizedSystems/RMEsite/RMEs_2.aspx (accessed Nov 22, 2016).

WHO. *Guidelines for Drinking Water Quality, 3rd ed.;* World Health Organization (WHO); Geneva, Switzerland, 2004; Vol. 1.

WHO. *Guidelines for Safe Recreational Water Environments: Coastal and Fresh Waters;* World Health Organization (WHO); Geneva, Switzerland, 2003; Vol. 1.

WHO. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater: Policy and Regulatory Aspects;* World Health Organization (WHO); Geneva, Switzerland 2006a; Vol. 1.

WHO. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater: Wastewater Use in Agriculture;* World Health Organization (WHO); Geneva, Switzerland, 2006b; Vol. 2.

WHO. *Quantitative Microbial Risk Assessment: Application for Water Safety Management*; World Health Organization (WHO); Geneva, Switzerland, 2016.

WHO. *Sanitation Safety Planning Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta.* World Health Organization (WHO); Geneva, Switzerland, 2015; p 138.

WHO. *Water Safety Plan Manual: Step-by-Step Risk Management for Drinking-Water Suppliers;* World Health Organization (WHO); Geneva, Switzerland, 2009.

Woods, G. J.; Kang, D.; Quintanar, D.R.; Curley, E.F.; Davis, S.E.; Lansey, K.E.; R.G. Arnold, R.G. Centralized versus Decentralized Wastewater Reclamation in the Houghton Area of Tucson, Arizona. *Journal of Water Resources Planning and Management* 2013, *139(3),* 313-324.

Appendix A: Criteria for Flushing Toilets and Performance-Based Standards

Examples of state regulations for flushing toilets with graywater and roof runoff are provided in Tables A-1 and A-2. Treatment standards to meet NSF 350 certification are provided in Table A-3.

Table A-1: Summary of State Regulations and Criteria for Flushing Toilets with Graywater (NRC, 2016)

State	BOD_5 (mg/L)	TSS (mg/L)	Turbidity (NTU)	Total Coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Disinfection
California	10	10	2	2.2	2.2	0.5 – 2.5 mg/L of residual chlorine
New Mexico	30	30	-	-	200	-
Oregon	10	10	-	-	2.2	-
Georgia	-	-	10	500	100	-
Texas	-	-	-	-	20	-
Massachusetts	10	5	2	-	14	-
Wisconsin	200	5	-	-	-	0.1 – 4 mg/L of residual chlorine
Colorado	10	10	2	-	2.2	0.5 – 2.5 mg/L of residual free chlorine

BOD_5 = 5-day biochemical oxygen demand. mg/L = Milligram per liter. TSS = Total suspended solids. NTU = Nephelometric turbidity unit. CFU = Colony forming unit. mL = Milliliter.

Table A-2: Summary of State Regulations and Criteria for Flushing Toilets with Roof Runoff (Compiled from NRC, 2016)

State	Turbidity (NTU)	*E. coli* (CFU/100 mL)	Total Coliforms (CFU/100 mL)
California	10	<100	-
Texas	-	<100	<500
Georgia	-	<100	<500

NTU = Nephelometric turbidity unit. CFU = Colony forming unit. mL = Milliliter.

Table A-3: Performance-Based Treatment Standards Required for Systems to Meet NSF 350 Certification (NSF, 2016)

Parameter	Unit	Class R[a]		Class C[b]	
		Test Average	Single Sample Maximum	Test Average	Single Sample Maximum
$CBOD_5$	mg/L	10	25	10	25
Total suspended solids	mg/L	10	30	10	30
Turbidity	NTU	5	10	2	5
E. coli	MPN/100 mL	14	240	2.2	200
pH	SU	6.0 – 9.0		6.0 – 9.0	
Storage vessel residual chlorine	mg/L	≥0.5 – ≤2.5		≥0.5 – ≤2.5	

[a] Class R: Flows through graywater systems are less than 400 gallons per day (gpd).

[b] Class C: Flows through graywater systems are less than 1,500 gpd.

$CBOD_5$ = 5-day carbonaceous biochemical oxygen demand. mg/L = Milligram per liter. NTU = Nephelometric turbidity unit. MPN = Most probable number. mL = Milliliter. SU = Standard unit.

References

NRC. *Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits*. National Research Council, National Academies Press: Washington, DC, 2016.

NSF (2016). *NSF/ANSI 350 and 350-1: Onsite Water Reuse.* Webpage of the National Sanitation Foundation. http://www.nsf.org/services/by-industry/water-wastewater/onsite-wastewater/onsite-reuse-water-treatment-systems (accessed Dec 2, 2016).

Appendix B: Estimating Exposure Volumes, Dose-Response, and Pathogen Concentrations

B1. Uncertainty in Exposure Volumes and Frequencies

There remains considerable uncertainty about the volume of water inhaled or ingested for the examined activities. Existing standards indicate that one can expect ingestion volumes per event to range from one drop of water (5×10^{-3} to 5×10^{-4} liters) to a mouthful 0.025 liters (child) (NRMMC et al., 2006, 2009; WHO, 2006). The Panel assumed the volume ingested follows: mouthful > ingestion of a drop(s) > hands to mouth (for adults) > inhalation. For the inhalation and hand to mouth exposures, the Panel made the conservative assumption of 100% recovery and/or partitioning leading to exposure.

The potential volume of water inhaled after toilet flushing likely is small, on the order of 10^{-9} liters (Lim et al., 2015). Accordingly, the value [0.01 milliliters (mL) or 10^{-5} liters] adopted in this framework from NRMMC et al. (2006) is likely a conservative estimate. Yet, there remain additional potential exposures due to accidental ingestion during household cleaning or repair activities.

The volume of water ingested due to clothes washing is highly uncertain. Again, the potential volume of water that is potentially inhaled after washing is likely small, probably less than during toilet flushing. However, there may be potential for hand-to-mouth exposure, and de Man et al. (2014) estimated a range of potential volumes ingested for adults assuming inputs similar to children. Assuming a mere second of hand-to-mouth exposure, the volume ingested is estimated 0.02 to 0.30 mL. The adopted value for this framework falls into the lower end of that range, and is further based on use of cyanuric acid uptake (Sinclair et al., 2016b) in reclaimed water used during car washing. Up to 0.1 mL (10^{-4} liters) exposure appears to be a maximum type of exposure (Sinclair et al., 2016a). Note that most pathogen contamination is due to soiled clothing and not the source water used to wash clothes, and hence is insignificantly different from when potable water is used.

For unrestricted irrigation and dust suppression, NRMMC et al. (2006) assumed the ingestion of 1 mL at 50 times a year, given that:

> "Most people use municipal areas sparingly (estimate one-half to three weeks). People are unlikely to be exposed directly to large amounts of spray and, therefore, exposure is from indirect ingestion via contact with lawns, etc. Likely to be higher when used to irrigate facilities such as sports grounds and golf courses (estimate once per week)."

Using these assumptions from de Man et al. (2014), this framework uses the following: 1.0 mL is equivalent to approximately 10 to 100 seconds of hand-to-mouth exposure.

The volume consumed during a cross-connection event corresponds to 1 day of potable consumption. The duration of the cross-connection and fraction of the population exposed is highly uncertain and likely variable. Nonetheless, unaware children may drink from a garden hose, and accidental cross-connection/backflow to drinking water has been reported in Australia (Storey et al., 2007). In addressing variability, for example, the fraction of the population with a cross-connection may be different for individual home treatment systems when compared with apartment complexes.

B2. Pathogen Dose-Response

Each pathogen has a unique dose-response relationship that relates consumers' dose to a probability of infection (Table B-1). For some pathogens (like *Giardia* and human adenovirus), there exists only one or two peer-reviewed model options. For others, like Rotavirus, the various options are similar (Teunis and Havelaar, 2000). For the remaining pathogens, multiple dose-response models can be used, each based on different assumptions and data, but not necessarily addressing the range in pathogen or host effects that affect the dose-response. All these options are discussed in Schoen et al. (2017).

The models chosen are summarized in Table 3-3 in Chapter 3, along with the fraction of the population considered susceptible to infection. See Van Abel et al. (2016), Bambic et al. (2011), and U.S. EPA (2014) for a full discussion and description of the issues related with selecting and using these models.

Given the potential importance of Norovirus in dominating final pathogen reduction targets, the Panel incorporated model uncertainty by presenting an upper-bound $\log_{10}$ reduction target (LRT), lower-bound LRT, and an "averaged" target that randomly weights the lower and upper bound models available, using a uniform distribution of weights (i.e., a weighted approach).

B3. Probabilistic Quantitative Microbial Risk Assessment for Health-Protective Pathogen Reduction Targets

The Panel used a Quantitative Microbial Risk Assessment (QMRA) to estimate health-protective (risk-based) pathogen reduction targets for each pathogen separately, corresponding to annual infection risk benchmarks of 10^{-4} and 10^{-2} per person per year (ppy). Pathogen reduction targets were estimated for untreated, "fresh" collected waters (i.e., waters without pathogen growth or decay in storage). The probabilistic QMRA approach was based on the traditional QMRA approach to calculate the annual probability of infection (U.S. EPA, 2014).

The probabilistic QMRA accounts for:

- Different ranges of users, each with a unique set of daily exposures (e.g., a small fraction of the total population of users exposed to a cross-connection event).
- Variation in pathogen density.
- Sporadic pathogen occurrence.

To estimate the pathogen $\log_{10}$ reduction target (LRT), the annual probability of infection for a set of activities (presented in Chapter 3) was solved to give the tolerable infection risk benchmarks of 10^{-4} or 10^{-2} ppy (Equation B-1).

Benchmark infection risk = $S * (1 - \prod_{n_i}[1 - DR\left(V_i * \ 10^{log_{10}(C) - \mathrm{LRT}}\right)$ (Equation B-1)

where: S is the fraction of people in the exposed population susceptible to each reference pathogen; DR(...) is a dose-response function for the reference pathogen; V_i is the volume of water ingested per day for the activity set *i* ; n_i is the number of days of exposure over a year for activity set *i*; and C is the pathogen concentration in the untreated, freshly collected source water.

Table B-1: Pathogen Dose-Response Relationships

Reference Pathogen	Model	Model Parameters	Parameter Values	Units[e]	Reference	Susceptible Fraction
Enteric Viruses						
Adenovirus Type 4	Exponential	r	0.4172	$TCID_{50}$	(NRMMC et al,. 2009) (Crabtree et al., 1997)	1
Norovirus (GI and GII.4)[a]	Fractional Poisson	P u	0.72 1106	gc	(Messner et al., 2014)	1
Rotavirus	Beta-Poisson	alpha beta	0.2531 0.4265	PFU	(NRMMC et al., 2009)	0.06
Enteric Bacteria						
Campylobacter jejuni[b]	Beta-Poisson	alpha beta	0.145 7.589	CFU	(NRMMC et al., 2009) (Haas et al., 1999)	1
Pathogenic *E. coli*[b]	Beta-Poisson	alpha beta	0.1778 1.78×10^6	CFU	(NRMMC et al., 2009)	0.06
Salmonella enterica[c]	Beta-Poisson	alpha beta	0.3126 2884	CFU	(NRMMC et al., 2009) (Haas et al., 1999)	1
Parasitic Protozoa						
Cryptosporidium spp. updated[d]	Fractional Poisson	P	0.737	oocysts	(Messner and Berger, 2016)	1
Giardia lamblia	Exponential	r	0.0199	cysts	(Rose et al., 1991)	1

[a] For Norovirus, the two dose-response models act as the lower and upper bounds of predicted risk across the range of available models.

[b] For *Campylobacter* and pathogenic *E. coli*, there are two dose-response models with different predicted risks. The Panel selected the models based solely on feeding studies for health adults, as well as alternative models based on analysis of outbreak data for children.

[c] For *Salmonella enterica,* the Panel selected the model proposed by Haas et al. (1999) because it is conservative among the options that are computationally easy to implement; however, this model does not include the two most common serotypes, which may be more infectious.

[d] For *Cryptosporidium*, the Panel selected an updated dose-response model, not the model adopted to develop the Long Term 2 Enhanced Surface Water Treatment Rule for drinking water (U.S. EPA, 2005).

gc = Genome copies, $TCID_{50}$ = Tissue culture infective dose (50%), PFU = Plaque-forming units, CFU = Colony-forming units.

A Monte Carlo analysis was used to capture the natural variation in the input parameters that affect daily exposure. The Panel simulated 10,000 possible years using Equation B-1, given that some exposure scenarios are rare on an annual basis. For each year, n_i, the number of exposure events for activity *i* for each reference pathogen; n_i is equal to the number of activity uses per year (Table 3-1) when pathogens are consistently present throughout the year. When pathogens are present a fraction of the days in the year, the number of exposure events (n_i) was sampled from a hypergeometric distribution without replacement with the number of observations set to the number of days out of the year that a reference pathogen is present in the collected onsite water.

For each year, the Panel generated n_i samples from the pathogen density *C* to solve Equation B-1. The ninety-fifth percentile LRT, rounded to one decimal point, is reported.

References

Bambic, D.; McBride, G.; Miller, W.; Stottand, R.; Wuertz, S. *Quantification of Pathogens and Sources of Microbial Indicators for QMRA in Recreational Waters*; Project No. PATH2R08; Water Environment Research Foundation (WERF): Alexandria, VA, 2011.

Crabtree, K.D.; Gerba, C.P.; Roseand, J.B.; Haas, C.N. Waterborne Adenovirus - A Risk Assessment. *Water Science and Technology* 1997, *35(11-12),* 1-6.

de Man, H.; van den Berg, H.H.; Leenen, E.J.; Schijven, J.F.; Schets, F.M.; Jvan der Vliet, J.C.; van Knapenand, F.; de Roda Husman, A.M. Quantitative Assessment of Infection Risk from Exposure to Waterborne Pathogens in Urban Floodwater. *Water Research* 2014, *48,* 90-99.

Haas, C.H., Rose; J.B.; Gerba, C.P. *Quantitative Microbial Risk Assessment*, 1st ed.; John Wiley and Sons: New York, NY, 1999.

Lim, K.-Y.; Hamilton, A.J.; Jiang, S.C. Assessment of Public Health Risk Associated with Viral Contamination in Harvested Urban Stormwater for Domestic Applications. *Science of the Total Environment* 2015, *523,* 95-108.

Messner, M.J., Berger, P.; Nappier, S.P. Fractional Poisson-A Simple Dose-Response Model for Human Norovirus. *Risk Analysis* 2014, *34(10),* 1820-1829.

Messner, M.J.; Berger, P. *Cryptosporidium* Infection Risk: Results of New Dose-Response Modeling. *Risk Analalysis* 2016, *DOI: 10.1111/risa.12541*.

NRMMC; EPHC; AHMC. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) - November 2006. Document No. 21 National Water Quality Management Strategy; Natural Resource Management Ministerial Council (NRMMC), Environment Protection (EPHC),Australian Health Ministers Conference (AHMC); Biotext Pty Ltd, Canberra: Australia, 2006.

NRMMC; EPHC; NHMRC. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse - July 2009; Document No. 23 National Water Quality Management Strategy; Natural Resource Management Ministerial Council (NRMMC), Environment Protection and Heritage Council (EHPC), National Health and Medical Research Council (NHMRC); Biotext Pty Ltd, Canberra: Australia, 2009.

Rose, J.B.; Haas, C.N.; Regli, S. Risk Assessment and Control of Waterborne Giardiasis. *American Journal of Public Health* 1991, *81,* 709-713.

Schoen, M.E.; Ashbolt, N.J.; Jahne, M.A.; Garland, J. Risk-Based Enteric Pathogen Reduction Targets for Non-Potable and Direct Potable Use of Roof Runoff, Stormwater, Greywater, and Wastewater. Microbial Risk Analysis [Online] 2017, *http://dx.doi.org/10.1016/j.mran.2017.01.002* (accessed March 3, 2017).

Storey, M.V.; Deere, D.; Davison, A.; Tam, T.; Lovell, A.J. Risk Management and Cross-Connection Detection of a Dual Reticulation System, Proceedings of the 3rd Australian Water Association 'Water Reuse and Recycling' Conference (Reuse2007), Sydney, Australia, July 16-17, 2007; Khan, S., Stuetz, R., Anderson, J.M., Eds.; UNSW Publishing and Printing Services, University of New South Wales: Sydney, 2007, pp 459-466.

U.S. EPA. *Occurence and Exposure Assesment for the Final Long Term 2 Enhanced Surface Water Treatment Rule;* EPA 815-R-06-002; United States Environmental Protection Agency (U.S. EPA) Office of Water: Washington, D.C., 2005.

U.S. EPA. *Microbiological Risk Assessment (MRA) Tools, Methods, and Approaches for Water Media;* EPA 820-R-14-009; United States Environmental Protection Agency (U.S. EPA A) Office of Water, Office of Science and Technology: Washington, D.C., 2014.

Van Abel, N.; Schoen, M. Meschke, J.S. Comparison of Risk Predicted by Multiple Norovirus Dose-Response Models and Implications for Quantitative Microbial Risk Assessment. *Risk Analysis* 2016, *DOI 10.1111/risa.12616*.

WHO. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater: Wastewater Use in Agriculture;* World Health Organization (WHO); Geneva, Switzerland, 2006; Vol. 2.

Appendix C: Applying the Monte Carlo Technique to Simulate Aggregate Treatment Train Performance

To apply the Monte Carlo approach, a random value is generated and used to sample from the probability distribution, which results in a LRV for the process. For multiple barriers systems, random values are generated for each process in the treatment train, and the LRVs from each simulation are summed together. By repeating the simulation many times (typically, 5,000 to 10,000 times), an aggregate probability distribution is obtained.

The process shown in Figure C-1 can be used to demonstrate the application of the Monte Carlo simulation process to obtain the aggregate cumulative probability distribution. A spreadsheet approach can be used to apply the Monte Carlo simulation technique. Spreadsheet columns are configured alternately for each process with a random number function and another function (i.e., LOGNORM.INV) is used to compute the $\log_{10}$ reduction achieved corresponding to the random value. The LRV achieved by each process for each iteration of the simulation is added together to obtain the overall LRT for the treatment train. Repeating the simulation many times results in a lognormal cumulative probability distribution for the treatment train (see Figure C-1).

As shown in Figure C-1 and the preceding analysis, the application of the Monte Carlo approach results in a similar overall treatment train LRV as summation of the lowest observed values and LRT_{05} methods. Refer to Table 4-7 in Chapter 4 for alternative design LRVs from the above analysis.

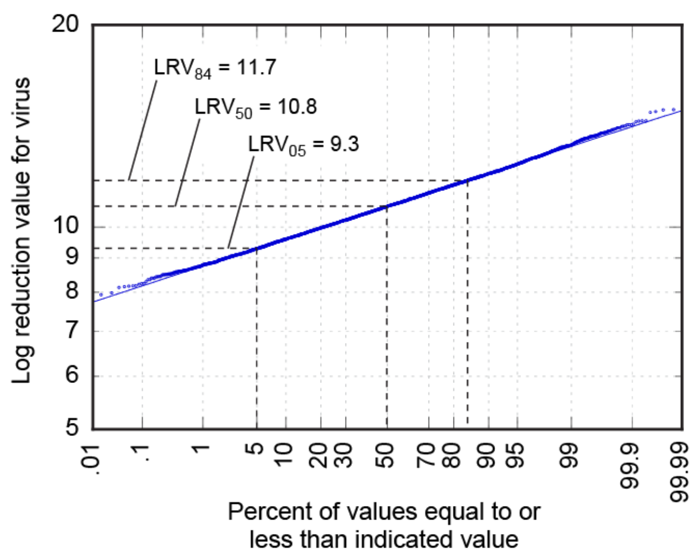

Figure C-1: Cumulative probability distribution for multiple barrier treatment train simulated using the Monte Carlo analysis technique.

Appendix D: Biographies of the Independent Advisory Panel Members

Panel Chair: Sybil Sharvelle, Ph.D. Sybil Sharvelle is an Associate Professor in Civil and Environmental Engineering at Colorado State University in Fort Collins, Colorado and a member of One Water Solutions. She received her doctoral degree from Purdue University, where she developed a biological processor for the treatment of graywater for potable reuse during long space missions. Through this project, Sharvelle gained experience in water reuse and closed-loop recycling of resources. This experience led to her current interest in sustainable water management. She has led projects funded by the Water Environment Research Foundation, WateReuse Foundation, and U.S. Environmental Protection Agency to study urban water systems, with particular focus on graywater reuse and water conservation. Sharvelle is a member of the National Research Council committee for beneficial use of graywater and stormwater.

Nicholas Ashbolt, Ph.D. Nick Ashbolt is a Professor in the School of Public Health at the University of Alberta in Canada. He has more than 25 years of experience working with water supply systems. His research focuses on next-generation municipal water services (drinking water, wastewater, stormwater) framed around resource recovery (i.e., water, energy, fertilizers) for improved eco-health and living conditions. Prior to joining the University of Alberta, he served as a research microbiologist for U.S. Environmental Protection Agency (U.S. EPA), and earned the U.S. EPA Office of Research and Development Bronze Awards for science in 2008, 2012, and 2013. He also was a professor in the School of Civil and Environmental Engineering at University of New South Wales–Sydney for 14 years. He has authored or co-authored more than 180 peer-reviewed journal articles and 30 book chapters. Ashbolt earned a Ph.D. in environmental microbiology from University of Tasmania in 1985.

Edward Clerico, M.S., P.E. Edward Clerico is CEO Emeritus of Natural Systems Utilities in Hillsborough, New Jersey. He is an innovator and entrepreneur in the field of sustainable water infrastructure, and is noted for his extensive work on distributed water reuse systems, which includes the first direct water reuse systems in residential buildings in the United States. Clerico was the Founder and President of Applied Water Management, Inc., and Alliance Environmental, LLC. He also served as CEO/COO/President of Natural Systems Utilities (NSU), one of the leading distributed water infrastructure companies in the United States. NSU also implemented the first renewable energy co-digestion biogas facility, in Ridgewood, New Jersey. Clerico also held executive roles with American Water, and is the owner/developer of Carriage Farm LLC, an organic farm that advances local and natural food practices. He holds B.S. and M.S. degrees from Rutgers University.

Robert Hultquist, P.E. Bob Hultquist retired from the California Department of Public Health and now serves as an environmental engineering consultant. He is a Civil Engineer with more than 45 years of experience in water quality and public health engineering. As an employee of the California Department of Public Health (CDPH), he regulated public water systems for 30 years, was responsible for revisions to the drinking water regulations and water recycling criteria, and developed standards for indirect potable reuse. Since retiring from CDPH, Hultquist has been assisting the California State Water Board with the development of additional potable reuse regulations.

Harold Leverenz, Ph.D., P.E. Harold Leverenz is a Research Engineer with the University of California, Davis, where he has been involved in modeling, designing, and evaluating technologies and processes for sustainable water management. His research focuses on decentralized and satellite water reuse systems, natural treatment systems, carbon footprint analysis, and source control systems for nutrient and energy recovery. He holds an undergraduate degree from Michigan State University in Biosystems Engineering and a doctorate in Environmental Engineering from University of California at Davis (UC Davis). Leverenz is a registered civil engineer in California and conducts research on water reuse in the Department of Civil and Environmental Engineering at UC Davis.

Adam Olivieri, DrPH, P.E. Adam Olivieri, the Vice-President of EOA, Inc. in Oakland, California, has 35 years of experience in the technical and regulatory aspects of water recycling, groundwater contamination by hazardous materials, water quality and public health risk assessments, water quality planning, wastewater facility planning, urban runoff management, and onsite waste treatment systems. He has served as a staff engineer with the California Regional Water Quality Control Board (San Francisco Bay Region); staff specialist (and Post-doctoral fellow) with the School of Public Health at the University of California, Berkeley; project manager and researcher for the Public Health Institute; and a consulting engineer.

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