THE Water Research FOUNDATION




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Onsite Non-Potable Water System
Guidance Manual

National Blue Ribbon Commission for Onsite Non-potable Water Systems

Onsite Non-Potable Water System

GUIDANCE MANUAL

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THE Water Research FOUNDATION

National Blue Ribbon Commission for Onsite Non-potable Water Systems

Trussell TECHNOLOGIES INC

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Definitions

Blackwater: Wastewater originating from toilets and kitchen sources including sinks and dishwashers.

District-Scale ONWS: The collection, treatment, and use of alternative source waters at a multiple-building, or neighborhood, scale.

Graywater: Wastewater collected from non-blackwater sources, such as bathroom sinks, showers, bathtubs, clothes washers, and laundry sinks.

Log Removal Target (LRT): The quantified pathogen reduction required to achieve the public health goal of maintaining the annual risk of infection at or below 1 in 10,000 people as defined by the Expert panel.

Log Removal Value (LRV): The quantified pathogen reduction "credit" assigned to different unit processes that make up a treatment train. When seeking to comply with a given set of LRTs, a treatment train must be designed to include unit processes that – when summed together – achieve an LRV equal to or greater than those LRTs.

ONWS: The collection, treatment, and use of alternative source waters at the building or neighborhood scale.

Roof Runoff: Precipitation from rain or snowmelt events that is collected directly from a roof surface 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). Stormwater includes runoff from roofs with frequent public access.

Acronyms

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BDOM	Biodegradable organic matter
BOD	Biological oxygen demand
CDPHE	Colorado Department of Public Health and Environment
CFU	Colony forming units
Commission	National Blue Ribbon Commission for Onsite Non-potable Water Systems
CT	Product of the disinfectant residual concentration (C) and the contact time (T)
DVGW	German Technical and Scientific Association for Gas and Water
EC	Electrical conductivity
GAC	Granular activated carbon
HPC	Heterotrophic plate count
HRT:	Hydraulic retention time
LRT(s)	log reduction target(s)
LRV	Log reduction value
LT2	Long Term 2 Enhanced Surface Water Treatment Rule
L/D	Pipeline contactor length (L) to diameter (D) ratio
MBR	Membrane bioreactor
MF	Micro-filtration
MLSS	Mixed liquor suspended solids
NWRI	National Water Research Institute
ONWS	Onsite Non-potable Water System
OSHA	Occupational Safety and Health Administration
O&M	Operations and maintenance
PDT	Pressure decay test
PLC	Programmable logic controller
QMRA	Quantitative microbial risk assessment
RO	Reverse osmosis
SDS	Safety data sheet
SOP	Standard operating procedure
SRT	Solids retention time
SWTR	Surface Water Treatment Rule
TMF	Technical, managerial, and financial capacity
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultra-filtration
UV	Ultraviolet light
UVDGM	Ultraviolet Disinfection Guidance Manual
UVT	Ultraviolet light transmittance
V/G/C/B	Virus, *Giardia*, *Cryptosporidium*, bacteria

1 Introduction

1.1 Onsite Water Reuse: An Expanding Opportunity

While the last several decades have witnessed significant investment in municipal-scale non-potable reuse systems, that approach is not feasible in all locations. Consequently, there is growing interest in the development of *onsite* non-potable water systems (ONWS) as an additional strategy to develop local, sustainable water supplies. ONWS involve collecting and treating alternate source waters at the building or neighborhood scale. ONWS can significantly offset the use of potable water in residential and commercial buildings, providing water that is fit for various non-potable end uses, such as toilet flushing and irrigation. ONWS can expand in new areas where it is too costly to build a centralized distribution network, and where existing wastewater collection and treatment infrastructure are at or near capacity. ONWS offers a way to diversify water supplies, improve stormwater management, and enhance the resilience of urban water systems.

Because ONWS is in its early stages of development, there is growing interest to create recommendations to aid in the consistent implementation of these programs. One of the first critical questions is: what level of treatment is required to make safe ONWS water? To answer this, the National Blue Ribbon Commission for Onsite Non-potable Water Systems (Commission) enlisted an Expert Panel to develop a framework for public health guidance. This panel concluded that controlling waterborne microbial pathogens was the key goal for treatment, and specified the level of pathogen reduction that would be required to safely use different types of water. They also provided recommendations for how these systems should be monitored to ensure that they were continuously protecting public health. The Commission included the Panel's recommendations in their recent *Guidebook for Developing and Implementing Regulations for Onsite Non-Potable Water Systems.*

This manual takes the next step by providing more detail for how to implement an ONWS project based on the public health regulations. These programs may be organized in many different ways, but all will entail multiple steps including the design, permitting, construction, operation, and maintenance of ONWS systems. While the specifics of any one program will vary, there are topics that are relevant for all ONWS systems. This Guidance Manual provides the fundamental background to implement an ONWS program that is in line with the Expert Panel's approach for public health protection.

The goal of this Guidance Manual is to provide guidance to ONWS stakeholders who are seeking to implement the risk-based public health framework and promote the safe design, operation, and permitting of ONWS systems.

1.2 What is Onsite Non-Potable Water?

In this Guidance Manual, onsite non-potable water systems are those that collect and treat source waters at a single-building or a multi-building scale (i.e., district scale) to produce water for non-potable needs such as irrigation, toilet flushing, cooling towers, clothes washing, and dust suppression. ONWS can be used to treat a variety of source waters that are produced or collected in buildings, including rainwater harvested from the roof, stormwater harvested at grade, graywater, blackwater, and foundation drainage (Figure 1).

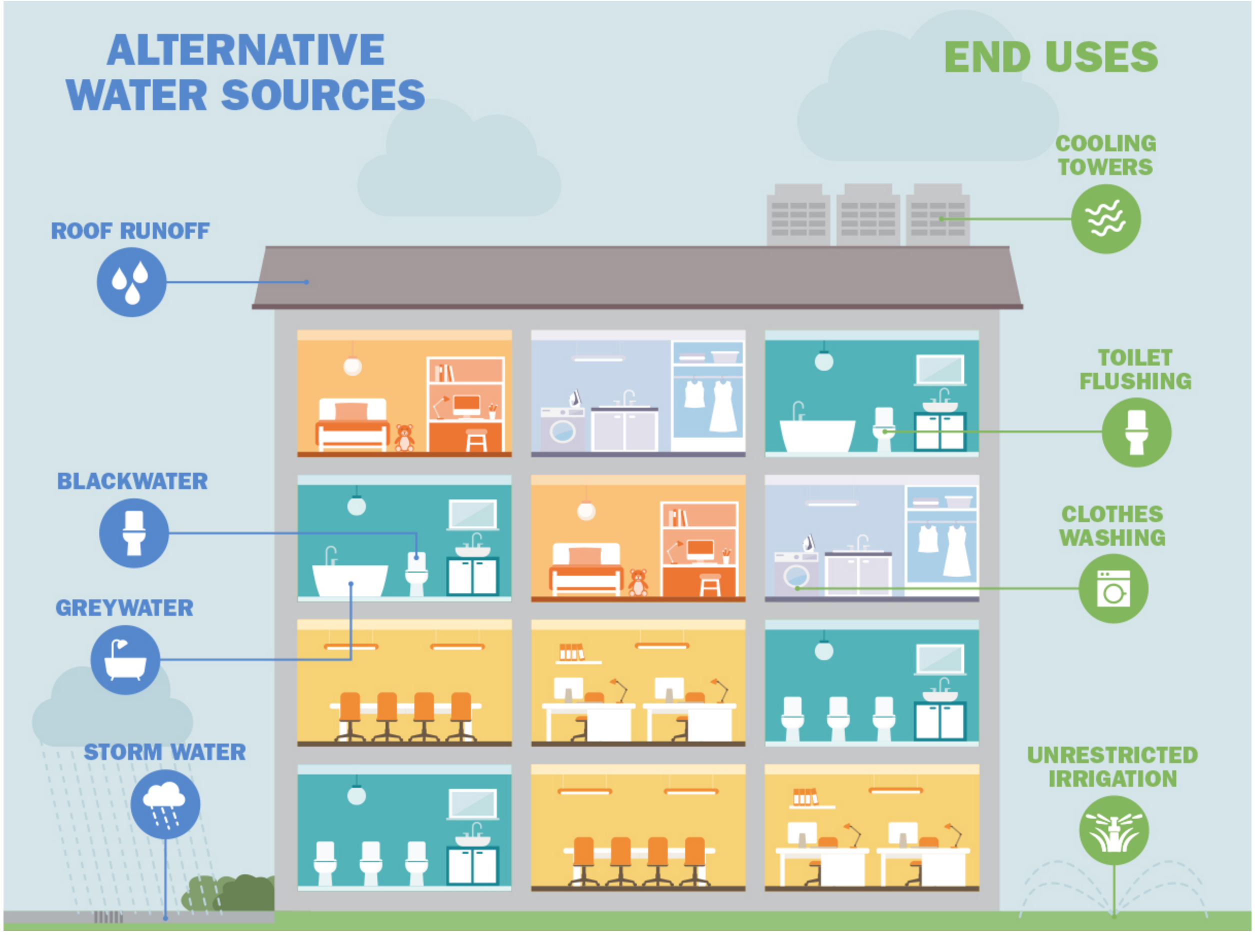


Figure 1. Source Waters and End Uses for Onsite Non-Potable Reuse.[1]

[1] Note that different jurisdictions may define these terms differently.

Key Terms:

- **Blackwater** is wastewater originating from toilets and kitchen sources including sinks and dishwashers.
- **Graywater** is wastewater collected from non-blackwater sources, such as bathroom sinks, showers, bathtubs, clothes washers, and laundry sinks.
- **Roof runoff** is precipitation from rain or snowmelt events that is collected directly from a roof surface not subject to frequent public access.
- **Stormwater** is precipitation runoff from rain or snowmelt events that flows over land and/or impervious surfaces (e.g., streets and parking lots). Stormwater includes runoff from roofs with frequent public access.

Public Health is the Top Priority

The top priority of all water systems is public health protection. To help ensure the safety of ONWS systems, the Commission convened an Expert Panel to determine how much pathogen reduction should be required to make the various source waters safe for their desired end uses. The Expert Panel developed targets for a diverse group of pathogens – viruses, protozoa (e.g., *Giardia* and *Cryptosporidium*), and bacteria – using "log reduction" as the metric. In this scheme, 1-log reduction corresponds to a 90% (e.g., 10-fold) reduction in pathogens, 2-logs is 99% (e.g., 100-fold), 3-logs is 99.9% (1,000-fold), and so on. Because the different source waters contain different amounts of pathogens (e.g., blackwater contains more than graywater), the Panel specified different log reduction targets (LRTs) for each. **Regardless of the source water used, the LRTs ensure that all waters receive sufficient treatment to be equally protective of public health.** The LRTs were developed to achieve one clear public health goal: maintain the annual risk of infection at or below 1 in 10,000 people, which is the most common benchmark for water in the U.S. Because human health risk underlies all of the treatment goals, the LRTs are referred to as *risk-based standards*. The LRTs do not result in water that is treated to potable standards; rather, they result in water that is fit for non-potable uses and presents the same de-minimis risk as potable drinking water.

With the public health targets in hand, the next step is to structure and implement ONWS programs around the LRT framework. The goal of this Guidance Manual is to help ONWS stakeholders implement safe onsite reuse systems.

1.3 Who Should Use This Guidance Manual?

Multiple types of stakeholders are needed to design, implement, and oversee ONWS. This manual focuses on five types of stakeholders based on the function that they serve. On one side are the **Program Administrators** and **Regulators** who are responsible for developing, overseeing, permitting, and administering the program. The other includes the Project Team including the **System Owners**, **Design Engineers**, and **Operators** who are planning, designing, constructing, operating, and maintaining individual ONWS projects.

Key Roles of Stakeholders:

- **Design Engineers** play an important role in many steps of the process. They need to understand the importance of public health protection, be capable of designing ONWS systems that can meet treatment and monitoring requirements, and effectively communicate with System Owners and Regulators to demonstrate that their systems can comply with requirements for ONWS permits.
- **Regulators** also serve multiple functions in the process, from reviewing design plans for proposed ONWS systems, determining the ability of systems to comply with public health requirements, permitting and inspecting ONWS systems, approving operations and maintenance plans, and reviewing compliance reports to ensure the reliable and safe ongoing operation of the system. In some cases, multiple Regulators may be involved in the various steps needed to permit and oversee ONWS.
- **Operators** must operate and maintain the ONWS system to ensure that the treatment goals are continuously obtained, and communicate the findings to the Regulators. Through proper operation, reporting, maintenance, and equipment replacement, they help ensure the long-term success of ONWS systems.
- **Program Administrators** are responsible for developing and administering ONWS programs, and frequently support staff involved in various implementation steps of an ONWS project (e.g., Regulators, inspectors). Administrators may include staff at multiple levels including city, district, organization, and watershed levels. Program Administrators may also serve other roles, including System Owner and Regulator.
- **System Owners** are frequently the owners of both the building and the ONWS system. For new ONWS projects, System Owners must assemble teams, including Design Engineers and Operators, to develop and implement the project. They may have varying degrees of responsibility in the implementation and permitting of a project.

1.4 Overview of Guidance Manual Chapters

The manual is divided into six chapters as described in Figure 2. This section provides a summary of the key topics covered in each chapter and highlights how the information covered relates to the stakeholder types.

CHAPTER 1: **Introduction**	Covers background on ONWS and provides overview of the guidance manual
CHAPTER 2: **Public Health Goals**	Describes the risk-based pathogen reduction targets and the importance of monitoring to verify treatment
CHAPTER 3: **Treatment Selection and Crediting**	Details various forms of treatment and how they can be used for pathogen reduction and water quality targets
CHAPTER 4: **Developing Multiple-Barrier ONWS Systems**	Provides considerations for designing effective treatment trains using multiple and diverse treatment processes to achieve water quality and treatment objectives
CHAPTER 5: **Operations Plan**	Highlights the importance of proper operations and maintenance (O&M) in effective public health protection and the critical elements of an O&M plan
CHAPTER 6: **Regulatory and Permitting Plan**	Describes an overall approach to project permitting with key regulatory interactions at multiple steps of design, construction, start-up, and on-going operations

Figure 2. Overview of Material Covered in the Six Chapters of the Guidance Manual.

Chapter 2: Public Health Goals Describes risk-based treatment performance targets and why they focus on microbial contaminants (pathogens) and not on chemicals. This section provides useful background for the **Program Administrators, Regulators,** and **Design Engineers** since it sets the benchmarks for public health protection. It outlines the risk-based approach used to derive the LRTs and shows the similarities and differences between ONWS and potable water supplies. Beyond specifying minimum treatment requirements, this chapter also describes how systems should be monitored and verified to ensure compliance with the treatment goals. Toward this end, this information is relevant for Regulators who will evaluate the performance and water quality reports provided by ONWS projects. Additional detail on operation and reporting is included in Chapter 5 and Chapter 6.

Chapter 3: Treatment Selection and Crediting Details the major forms of treatment – biological treatment, filtration, and disinfection – and how they can be used to obtain credit toward the LRTs. The issue of crediting treatment processes (i.e., assigning a pathogen log reduction value) is critical since it will often drive the design and selection of unit processes. Beyond the LRTs, this chapter discusses other water quality goals and how unit processes can be selected to achieve them. This chapter is fundamental for **Design Engineers** and **Regulators** who will need to develop and permit treatment systems meeting these criteria.

Chapter 4: Developing Multiple-barrier ONWS Systems Most often there is not a single unit process that can provide protection against all of the pathogen groups and also meet all of the water quality objectives. Consequently, treatment trains typically require the use of multiple barriers, including both treatment and non-treatment barriers. This section describes considerations for the development of treatment systems able to treat different types of source waters. This chapter is critical for **Design Engineers, Operators,** and **Regulators** to ensure that the system can meet all of the treatment objectives.

Chapter 5: Operations Plan Provides an overview of the operations and maintenance (O&M) activities required once the system is constructed. The scope of this chapter spans from start-up and commissioning, through operations and reporting, to maintenance and trouble-shooting. This is a key chapter for **Program Administrators, Operators, Design Engineers,** and **Regulators** since it focuses on the consistent high performance of the system and the demonstration of appropriate public health protection.

Chapter 6: Regulatory and Permitting Plan There are multiple steps in the implementation process of ONWS systems. Each step provides an opportunity for regulatory involvement to evaluate the safety of the project. This section is tailored for **Regulators** and describes an overall approach to project permitting with key regulatory interactions at multiple steps of design, construction, start-up, and during ongoing operations. This chapter is also relevant for **Program Administrators, Design Engineers** and **Operators** who will interact with the Regulators to design, construct, commission, and operate ONWS systems.

Given the breadth of topics and the multiple functions that stakeholders must serve, it is unlikely that any single person will have expertise in the entire implementation process. As a result, coordinated teams will be needed both to administer programs and implement projects. **Program Administrators** and **System Owners** can serve an important role in the overall success of ONWS programs by ensuring that their teams of **Regulators**, **Design Engineers**, and **Operators** have the appropriate experience and understanding for the safe implementation of ONWS. This Guidance Manual is designed to help these stakeholders build their fundamental knowledge for ONWS.

1.5 How Do I Use This Guidance Manual?

The goal of this manual is to provide guidance to ONWS stakeholders who are seeking to implement the risk-based public health framework and promote the safe design, operation, and permitting of ONWS systems. Table 1 provides a roadmap for navigating this Guidance Manual that defines the recommended level of knowledge for each stakeholder type. While all stakeholders benefit from the broader vision obtained through a complete understanding of this Guidance Manual, each group should – at minimum – focus on the chapters most relevant to their roles, identified in Table 1 as 'detailed' and 'expert' levels. Each stakeholder should strive to have a general understanding of all chapters, while particular stakeholders should have more detailed or expert understanding of specified chapters. At times, one entity may serve multiple roles, such as when a Program Administrator is also a) the owner of an ONWS system and/or b) the Regulator. In other cases, the ONWS Design Engineer may also serve as the Operator. In such cases, stakeholders should follow the roadmaps for each of the individual functions that they are fulfilling.

Table 1. Roadmap for Each of the Five ONWS Stakeholders with Guidance Manual Recommendations.

	Design Engineer	Regulator	Operator	Program Administrator	System Owner
Chapter 1: Introduction	General	General	General	General	General
Chapter 2: Public Health Goals	Detailed	Expert	General	Detailed	General
Chapter 3: Treatment Selection and Crediting	Expert	Detailed	General	General	General
Chapter 4: Developing Multiple-Barrier ONWS Systems	Expert	Detailed	Detailed	General	General
Chapter 5: Operations Plan	Expert	Detailed	Expert	Detailed	General
Chapter 6: Regulatory and Permitting Plan	Detailed	Expert	Detailed	Detailed	General

Knowledge Level: General | Detailed | Expert

A basic knowledge of all aspects covered in this Guidance Manual would be helpful for any stakeholder, but particularly for the Program Administrator and System Owner. Although these stakeholders are not expected to be experts in any aspect of ONWS, they will interact with multiple stakeholder types throughout the implementation of an ONWS project, and so benefit from a general understanding of the roles each stakeholder fills. The Program Administrator, for example, should have a detailed understanding of the public health goals and risk-based framework described in Chapter 2 so that they can develop program components that facilitate effective communication between the System Owner, Regulator, and Design Engineer, ensuring that public health goals are met. If System Owners have a general understanding of each chapter in this Guidance Manual, they can understand the importance of selecting qualified people to guide the permitting, design, operation, and monitoring of these systems.

The Benefits of Knowledgeable Owners

SYSTEM OWNER

The System Owner is ultimately responsible for the proper design and operation of their ONWS system. Therefore, general understanding of the design approach can help the System Owner make educated decisions about the risk they're willing to accept (e.g., system uptime and reliability) and the trade-offs between capital and operating costs.

The Benefits of Knowledgeable Program Administrators

PROGRAM ADMINISTRATOR

The Program Administrator may serve as the link between the different stakeholders and facilitate communication between the relevant parties. If the Program Administrator has a general understanding of all the key concepts of ONWS, they can more effectively bridge the knowledge gaps between the stakeholders. Additionally, one stakeholder type may be made up of multiple entities that do not normally communicate outside of the ONWS setting (e.g., regulators responsible for public health aspects may be separate from those undertaking plumbing plan inspections). Having a Program Administrator that is aware of the different entities that have a stake in the ONWS program can better facilitate communication between the groups, streamlining the implementation process.

To further define the appropriate knowledge level for each stakeholder type, key learning objectives have been specified in Figure 3. In addition, detailed learning objectives for the stakeholder types are also included at the start of each chapter.

Key Learning Objectives	
DESIGN ENGINEER	• Basic requirements for public health protection in ONWS systems • Importance of pathogen control and LRTs • Need for the protection of water quality in the distribution system • Application of treatment process validation and pathogen crediting • Treatment process design for compliance with LRTs • Benefits of treatment and management barriers for public health protection • Routine monitoring data collection requirements for ongoing LRT compliance • Typical steps in the regulatory process • Key documents needed from Design Engineers for permitting • Importance of interactions with the Regulators
REGULATOR	• Detailed understanding of requirements for public health protection in ONWS • Derivation of LRTs and the importance of pathogen control • Existing pathogen crediting frameworks • Treatment design and monitoring strategies for compliance with LRTs • Evaluation of routine monitoring data for ongoing LRT compliance • Benefits of treatment and management barriers for public health protection • Treatment & monitoring strategies for source and end use combinations • Importance of interface between design, permitting, and operations • Documents for operations, reporting, commissioning, and worker safety • Role in start-up, commissioning, and ongoing monitoring of ONWS systems • Typical steps in the regulatory process • Key documents needed from project team for permitting
OPERATOR	• Key treatment and monitoring concepts • Role of operations in ensuring LRTs are continuously met • Importance of interface between design, permitting, and operations • Role in start-up, commissioning, and ongoing operations of ONWS systems • Documents for operations, reporting, commissioning, and safety • Staffing needs for ONWS systems
PROGRAM ADMINISTRATOR	• Basic requirements for public health protection in ONWS systems • Importance of pathogen control and LRTs • Documents for operations, reporting, commissioning, and worker safety • Typical steps in the regulatory process • Importance of interaction between Regulators and the project team
SYSTEM OWNER	• Basic requirements for public health protection in ONWS systems • Importance of interface between design, permitting, and operations • Benefits of treatment and management barriers for public health protection • Typical steps in the regulatory process • Documents for operations, reporting, commissioning, and worker safety

Figure 3. The Key Learning Objectives for the Five Stakeholders.

1.6 ONWS Implementation is a Multi-Step Process

There are many steps to implement an ONWS program. These steps ensure proper communication between the two main groups – those overseeing the program and those implementing actual projects – throughout the process. While the specifics may vary between programs, there are a number of essential elements that should be included in all successful programs. An overview of an implementation plan described in the Commission's *Guidebook* is presented in Figure 4, along with the stakeholders that serve key roles in each step.

While they do not need to understand all of the elements in this Guidance Manual, **Program Administrators and System Owners should understand the importance of hiring well-trained staff who have the knowledge and capacity to fulfill the roles outlined in the Guidance Manual**. Doing so will ensure that ONWS systems are designed, permitted, constructed, and operated safely.

PROGRAM SETUP

- Convene a working group
- Define rules and regulations
- Identify how regulations will be implemented and enforced

INITIAL PROJECT DEVELOPMENT

- Project Application
- Review and approve Project Application

PRELIMINARY DESIGN

- Preliminary design
- Engineering Report (Preliminary)
- Regulatory review of Preliminary Engineering Report

FINAL DESIGN, CONSTRUCTION AND INITIAL INSPECTIONS

- 100% Design
- Engineering Report (Final)
- Operations and Maintenance Plan including Commissioning Plan
- Construction
- Cross-Connection inspection
- Regulatory review and issuance of Permit to Operate

PROJECT STARTUP

- Installation Inspection
- Commissioning
- Regulatory review and issuance of Permit to Use

ON-GOING MONITORING AND REPORTING

- On-going monitoring and reporting
- Performance & water quality data review
- Inspections and enforcement
- Periodic permit renewal

Figure 4. Potential Implementation Steps in an ONWS Program and Stakeholders Leading Each Step.

1.7 Guidance Manual Assumptions

The goal of this manual is to educate stakeholders on how to design, permit, and operate ONWS systems that can achieve the risk-based pathogen LRTs. It should be emphasized, however, that this manual is *not* intended to be a comprehensive description of all information needed for ONWS stakeholders.

Assumed Stakeholder Experience

The manual assumes that stakeholders have a minimum degree of training and experience in their respective fields. While this experience does not need to be directly with ONWS, it should be of a similar nature so that the fundamental concepts of design, permitting, and operation are already understood. The minimum experience level for the various stakeholders is described in Table 2.

Table 2. Assumed Stakeholder Experience.

Stakeholder	Assumed Minimum Experience
Design Engineer	Professional Engineer with previous experience in the design of wastewater, recycled water, or drinking water treatment. Experience may be either at building-scale or municipal-scale. Design Engineer should be familiar with the control of pathogenic microorganisms.
Regulator	Previous experience regulating wastewater or drinking water systems (*optimal*), or other programs with similar public health goals (e.g., food safety, air quality, etc.). Familiarity with the control of pathogenic microorganisms. Experience in the review of permitting documents including engineering reports and operations & maintenance plans.
Operator	Previous experience operating treatment systems in wastewater, recycled water, and/or drinking water. Basic understanding of pathogen control and public health protection. Meet operator certification requirements, as required by the Regulator.
Program Administrator	Understanding of all the basic elements of ONWS (e.g., design, public health, permitting, and operations).
System Owner	Understanding of all the basic elements of ONWS (e.g., design, public health, permitting, and operations).

Limits of Guidance Manual Scope

There are several topics that are highly important for the successful implementation of ONWS that are specifically not covered in this manual. These include:

- **Cross connection and backflow prevention:** Preventing cross connections between ONWS systems and potable water systems is critical for public health protection. Requirements are often specified in state and/or local plumbing codes, and may include labeling, signage, backflow testing, and color coding pipes and appurtenances used for non-potable water. While this topic is not covered, other resources are available that provide guidance on appropriate cross connection measures and backflow prevention devices that can be used for these types of systems.

- **Aesthetic considerations:** Color and odor issues can be a problem for public acceptance, particularly if ONWS systems are producing water for end uses with public exposure, such as toilet flushing. Color and odor management is not explicitly addressed in the Guidance Manual; however, if treatment processes can also provide benefits in terms of color and odor control, it will be mentioned in Chapter 3.
- **Residuals handling:** The use of biological treatment, filtration, and other treatment technologies can result in the generation of residuals including both solid waste and brine streams. Residuals handling strategies will not be discussed in this document but should be incorporated into design and operation of ONWS systems.
- **Technical, managerial, and financial (TMF) capacity:** Since the 1996 Federal Safe Drinking Water Act, water suppliers have needed to possess adequate technical, managerial, and financial (TMF) capacity to assure the delivery of pure, wholesome, and potable drinking water. Similar requirements have been imposed on other recycled water projects, with requirements to demonstrate that a project applicant has sufficient (a) technical capacity to design and operate a treatment system, (b) managerial capacity to own, operate, and maintain the system, and (c) sufficient financial capacity to cover the costs associated with the operation, maintenance, and upkeep of the system. The topic of TMF may be of interest in the development of ONWS programs to further ensure the long-term success of ONWS operations.
- **Regulatory capacity:** In addition to TMF capacity, ONWS programs also require a high degree of regulatory capacity to ensure the systems are compliant with the risk-based treatment standards on an ongoing basis. This document will discuss the regulatory permitting process, as well as ongoing regulatory oversight requirements to ensure compliance, but will not explicitly address the regulatory capacity needed for ONWS implementation.

1.8 Additional Resources for Chapter 1 Topics

ONWS Program Development

National Blue Ribbon Commission (2016). Blueprint for Onsite Water Systems: A Step-by-Step Guide for Developing a Local Program to Manage Onsite Water Systems. https://sfwater.org/modules/showdocument.aspx?documentid=6057.

National Blue Ribbon Commission (2017). A Guidebook for Developing and Implementing Regulations for Onsite Non-potable Water Systems. US Water Alliance, WE&RF, and WRF.

National Blue Ribbon Commission (2017) Model Local Ordinance for Onsite Non-potable Water Programs. http://uswateralliance.org/initiatives/commission/resources.

National Blue Ribbon Commission (2017) Model Program Rules for Onsite Non-Potable Water Programs. http://uswateralliance.org/sites/uswateralliance.org/files/MODEL%20PROGRAM%20RULES_FINAL.docx.

National Blue Ribbon Commission (2017) Model State Regulation for Onsite Non-potable Water Programs. http://uswateralliance.org/initiatives/commission/resources.

National Blue Ribbon Commission (2018) Making the Utility Case for Onsite Non-potable Water Systems. http://uswateralliance.org/sites/uswateralliance.org/files/publications/NBRC_Utility%20Case%20for%20ONWS_032818.pdf.pdf.

San Francisco Department of Public Health (2017) Director's Rule and Regulations Regarding the Operation of Alternate Water Source Systems. https://www.sfdph.org/dph/files/EHSdocs/ehsWaterdocs/NonPotable/SFHC_12C_Rules.pdf.

William J. Worthen Foundation (2018) Onsite Non-Potable Water Reuse Practice Guide.

Public Health Framework for ONWS

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H. and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

1.9 Resources for Additional Topics

Cross-Connection and Backflow Prevention

AWWA (2015) M14 Backflow prevention and cross-connection control: recommended practices, 4th edition.

EPA (2003) Cross-connection control manual. EPA 816-R-03-002. Office of Water, Office of Ground Water and Drinking Water, Washington, D.C.

San Francisco Public Utilities Commission (2017) Required Levels of Backflow Protection for Onsite Water Reuse Systems. https://www.sfdph.org/dph/files/EHSdocs/.ehs Crossflowdocs/Required_Backflow_Protection_for_Onsite_Water_Reuse_Systems.pdf

University of Southern California (2009) Manual of Cross-Connection Control, 10th Edition. Foundation for Cross-Connection Control and Hydraulic Research (Ed.).

Aesthetic Considerations

Jjemba, P., Johnson, W., Bukhair, Z., LeChevallier, M. (2015) Develop Best Management Practices to Control Potential Health Risks and Aesthetic Issues Associated with Reclaimed Water Storage and Distribution (WRRF 11-03). Alexandria, VA, 2015.

Technical, Managerial and Financial Capacity

State Water Resources Control Board (2019) Capacity development. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/TMF.html.

EPA (2017) Technical, managerial, and financial (TMF) capacity for small drinking water systems. https://www.epa.gov/dwcapacity/technical-managerial-and-financial-tmf-capacity-resources-small-drinking-water-systems-0.

2 Public Health Goals

This chapter addresses the key learning objectives for the Design Engineer and Regulator related to the public health goals of ONWS. The specific learning objectives for this chapter are shown in Figure 5.

Chapter 2 Key Learning Objectives	
DESIGN ENGINEER	• Basic requirements for public health protection in ONWS systems • Importance of pathogen control and log reduction targets (LRTs) • Need for the protection of water quality in the distribution system
REGULATOR	• Detailed understanding of requirements for public health protection in ONWS system • Derivation of LRTs and the importance of pathogen control
PROGRAM ADMINISTRATOR	• Basic requirements for public health protection in ONWS systems • Importance of pathogen control and LRTs

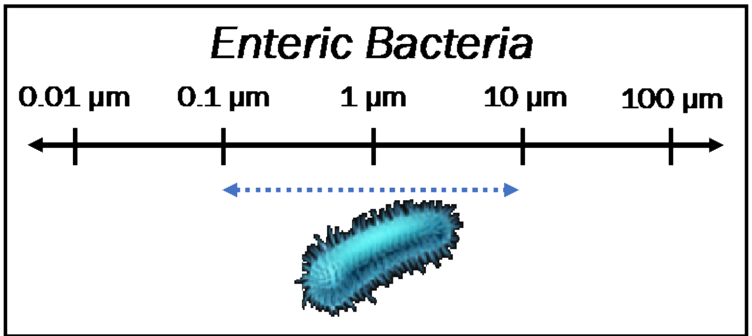
Figure 5. Chapter 2 Key Learning Objectives.

2.1 Controlling Pathogenic Microorganisms

One of the first questions that arises when developing a new program like ONWS is: what treatment is required to make the water safe? The absence of treatment standards was identified as a knowledge gap early on by the Commission, who responded by engaging a panel of experts to address this issue. The Expert Panel began by identifying which types of contaminants were the most important public health issues in a non-potable application. In general, the two major contaminant groups of concern are *enteric pathogenic microorganisms,* i.e., those that cause gastrointestinal illness, and *toxic chemicals*. Enteric pathogens include commonly known organisms like bacteria (such as *Salmonella* and pathogenic *E. coli*), viruses (such as enterovirus and norovirus), and protozoa (such as *Giardia* and *Cryptosporidium*). Toxic chemicals can include a wide diversity of contaminants from metals (e.g., chromium and arsenic), to cleaning products, pesticides, and pharmaceuticals and personal care products.

One of the principal ways in which these two contaminant groups differ is in the level of exposure needed to cause a health effect. Most toxic chemicals – particularly at the low concentrations found in recycled water – would only cause health effects after continuous long-term exposure at levels above public health concern. Consequently, toxic chemicals are approached from the standpoint of understanding chronic exposure, meaning that short-term variability is less important than the average, long-term exposure. Pathogens, on the other hand, can cause an infection in as little as a single exposure. Pathogens pose an acute threat since they can lead to health effects within hours or days of exposure.

This distinction between chronic and acute threats is important for ONWS because this water is not designed for potable end uses. As a result, one can assume that users will not have sustained exposure to significant volumes of ONWS water (i.e., via ingestion). The Expert Panel concluded that the health effects of toxic chemicals would be negligible without this exposure. Inadvertent exposure to small quantities of ONWS water could, however, be sufficient for the initiation of pathogen infections. Consequently, the Expert Panel focused their treatment requirements on the control of pathogens.



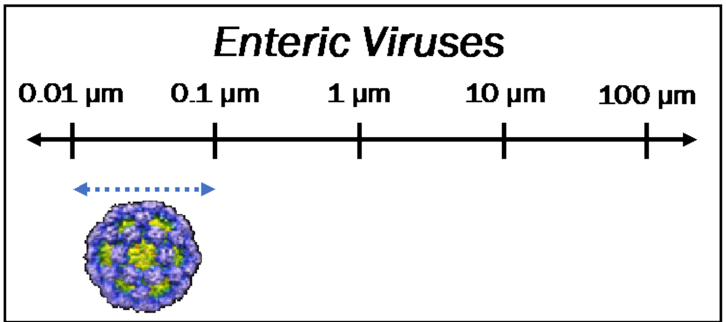
Examples	*E. coli, Salmonella, Campylobacter*
Size	Generally larger than viruses and smaller than protozoa
Physical removal	Intermediate size allows for moderate to high removal by filtration technologies
Disinfection	Susceptible to many forms of disinfection including chlorine, chloramine, and UV

2.2 What Are Risk-Based Standards?

What level of treatment is sufficient to make water acceptable for ONWS? Ideally, the concentration of pathogens could be reduced so that the threat of infection drops to zero. This situation is unattainable as there will always be *some* risk that exposure will lead to an infection. The risk can, however, be reduced down to acceptably low levels. **To make water suitable for ONWS, risk-based treatment standards were developed to reduce the concentration of pathogens down to acceptable levels.**

During an analysis conducted by the EPA in support of the Surface Water Treatment Rule, a 10^{-4} annual risk of infection for an individual consuming the water was presumed to be an acceptable level of risk (Regli et al., 1991) and this level has received widespread support in the U.S. water community. It is a *de facto* goal for many drinking water contexts and is the explicit goal in many potable reuse contexts (Hultquist, 2016; State Water Resources Control Board, 2018). This 1 in 10,000 (10^{-4}) risk of infection per person per year is the same level determined by the expert panel to be appropriate for ONWS as well. Meeting the requirements in Table 3 decreases the annual risk of infection to 10^{-4} through potential exposure to ONWS water.

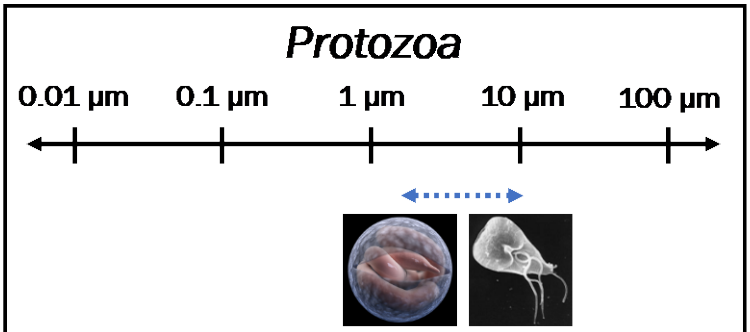
Does this mean that ONWS water is as safe to drink as drinking water? No. ONWS water is a fit-for-purpose water whose treatment has been tailored for its intended end uses – such as toilet flushing and irrigation. Users of ONWS water are exposed to some risk through non-potable applications, via small volumes from toilet flushing and irrigation. When treatment is applied correctly, the risk of infection is controlled to the acceptable 10^{-4} level. On the other hand, consumers of drinking water are exposed to much larger quantities of water (typically 2 L consumed per person per day). To maintain the same low level of risk in these two scenarios, drinking water must be treated to much stricter standards. Nevertheless, the risk associated with the non-potable use of ONWS is equivalent to the de facto goal for drinking water: 10^{-4} infections per person per year.



Examples	Enterovirus, norovirus, hepatitis A
Size	Typically 10- to 1000-fold smaller than bacteria and protozoa
Physical removal	Small size makes physical removal challenging (e.g., filtration)
Disinfection	Susceptible to chlorine and ozone disinfection, but more resistant to UV than bacteria and protozoa

2.3 What Level of Treatment is Required?

Log reduction targets (LRTs) for multiple pathogen types in each of the different source waters were developed using a risk-based methodology. An LRT of 1 represents a 1-log reduction requirement (or 90% reduction), 2 represents a 2-log (or 99% reduction), and so forth. The relevant pathogen groups are enteric viruses, parasitic protozoa (including *Giardia* and *Cryptosporidium*), and bacteria. It is worth noting that the U.S. EPA's drinking water requirements under the Safe Drinking Water Act also regulate the same groups of pathogens: enteric virus, heterotrophic plate count (HPC) bacteria, *Legionella*, and *Giardia* under the 1989 Surface Water Treatment Rule, *Cryptosporidium* under the 2006 Long Term 2 Enhanced Surface Water Treatment Rule, and coliform bacteria under the 2013 Revised Total Coliform Rule.



Examples	*Cryptosporidium, Giardia, Toxoplasma*
Size	Significantly larger than virus and generally larger than bacteria
Physical removal	Larger size allows for greater removal by physical processes (e.g., filtration)
Disinfection	Less susceptible to chemical disinfectants than other pathogens (particularly *Cryptosporidium*), though generally sensitive to UV disinfection

To develop the LRTs, the Panel utilized quantitative microbial risk assessment (QMRA) to relate human health risk with exposure to microbial hazards in the non-potable water supplies. Starting with assumptions about acceptable levels of risk, the Panel calculated the acceptable level of pathogens in the final ONWS effluent. By comparing these treated-water concentrations to the concentrations of pathogens in the different source waters, they estimated the degree of treatment (i.e., LRTs) required to ensure public health protection. The Panel determined LRTs for two different risk goals: a) a 1 in 10,000 (10^{-4}) infections per person per year level, and b) a 1 in 100 (10^{-2}) infections per person per year level. In the process of developing the Guidebook for Developing and Implementing Regulations for ONWS, the Commissioners came to the consensus to recommend LRTs associated with the targeted risk benchmark of 10^{-4}. The Guidance Manual therefore focuses its discussion on this risk goal.

The degree of pathogenic microorganisms present depends on the source water, with the highest concentrations expected in fecally contaminated waters such as blackwater. Accordingly, the LRT requirements are source-water-dependent. The LRTs for blackwater, graywater, stormwater, and roof runoff water for use in both unrestricted irrigation and indoor use are presented in Table 3. Because the exposures are not equivalent for the two end uses, the recommended LRTs differ slightly, with higher pathogen reductions needed for indoor use compared to the irrigation use scenario. For ONWS using multiple source waters, the systems need to be designed to meet the most stringent LRTs. For example, blackwater source waters are associated with higher LRT recommendations compared to stormwater.

Table 3. Log Reduction Targets (LRTs) for Onsite Non-Potable Reuse Systems Based on 10^{-4} Risk Goal.

Water Use Scenario	Enteric Viruses	Parasitic Protozoa	Enteric Bacteria
Domestic Wastewater/Blackwater			
Unrestricted irrigation	8.0	7.0	6.0
Indoor use[1]	8.5	7.0	6.0
Graywater			
Unrestricted irrigation	5.5	4.5	3.5
Indoor use	6.0	4.5	3.5
Stormwater (10% wastewater contribution[2])			
Unrestricted irrigation	5.0	4.5	4.0
Indoor use	5.5	5.5	5.0
Stormwater (0.1% wastewater contribution[2])			
Unrestricted irrigation	3.0	2.5	2.0
Indoor use	3.5	3.5	3.0
Roof runoff water			
Unrestricted irrigation	N/A	No data	3.5
Indoor use	N/A	No data	3.5

1. The ONWS Expert Panel evaluated the following indoor uses in the development of the LRTs: toilet flushing, clothes washing, and cross-connection with drinking water or direct ingestion of treated non-potable water.
2. LRTs are based on the assumption that the dominant contributor of pathogens in stormwater is contamination with municipal wastewater. The different stormwater LRT scenarios represent different contributing fractions of municipal wastewater.

2.4 Protecting Water Quality in the Distribution System

As previously discussed, the LRTs define the goals to reduce the concentrations of pathogens in the various source waters down to acceptable levels in the treated ONWS water. The pathogens of interest that the Expert Panel selected – enteric virus, bacteria, and protozoa – are mainly associated with fecal contamination. Consequently, higher levels of treatment are required for source waters with higher risk of fecal contamination (e.g., blackwater vs. graywater, and stormwater with more or less municipal wastewater contribution). Reducing the concentration of these pathogens in the treated water should ensure that they will not increase at the time of use.

While enteric virus and protozoa will not regrow outside of their hosts, some types of bacterial pathogens can present water quality challenges in the distribution system. Non-potable recycled water can have concentrations of biodegradable organic matter (BDOM) that can promote regrowth by both 1) reacting with and depleting disinfectant residuals, and 2) providing an energy source for microbial growth. These conditions can lead to microbial regrowth in recycled water distribution systems. The degradation of water quality while it resides in such distribution systems is an issue that may have significant implications for both public health and the aesthetic acceptability of ONWS.

Regrowth can present risks to public health if conditions promote the growth of opportunistic pathogenic microorganisms such as *Legionella pneumophila*, *Mycobacterium avium* and *Pseudomonas aeruginosa.* Of particular concern is *Legionella*, a respiratory pathogen that can grow in plumbing and be aerosolized during toilet flushing, spray irrigation, and in cooling towers–in any environment where warm aerosols are common. Maintaining microbial stability in the distribution system should be considered a high priority in the implementation of non-potable reuse systems. Meeting the pathogen control requirements during treatment is the first and most important step toward ensuring public health protection in ONWS systems. The Expert Panel also emphasized that the initial pathogen control treatment must be coupled with proper management in the storage and distribution of waters for full protection.

Consistent with drinking water systems, the Panel recommended that opportunistic pathogens be controlled by post-treatment management procedures for storage and distribution[2]. Their recommendations included:

- Producing well-treated water low in organics (carbonaceous material) and nutrients.
- Producing disinfected non-potable water.
- Using biologically stable construction material.
- Maintaining disinfectant residuals in the distribution system.
- Cleaning tanks and flushing the distribution system.
- Controlling temperature.

The Expert Panel recommended that stakeholders should review published guidelines for managing *Legionella* in distribution systems and implement appropriate actions. Additional information on maintaining microbial stability in the distribution system can be found in the Chapter 3 section on distribution system management and in the Additional Resources at the end of Chapter 2.

2.5 Summary of Public Health Goals

The goal of Chapter 2 is to describe the importance of controlling pathogenic microorganisms in ONWS systems to ensure the protection of public health. The Expert Panel's concept of risk-based standards was introduced, along with the idea of treating alternative source waters to the level fit for their intended use. To minimize the risk associated with using the water, LRTs were introduced as a way to quantify the treatment needed to make the water safe, as well as a tool to use in the design of safe ONWS systems. A key takeaway from this concept is that the LRT requirements will depend on the source water quality and the intended end use. For example, treating blackwater for toilet flushing has higher LRT requirements than treating rainwater for toilet flushing because there are more pathogens in blackwater, and therefore more treatment is required to minimize public health risks.

[2] Note that similar precautions are needed in conventional potable water storage and distribution systems as well.

2.6 Additional Resources for Chapter 2 Topics

Public Health Guidelines and Risk-Based Targets

EPA (1989) Surface Water Treatment Rule. 40 CFR 141.70-141.75. Washington, D.C.

EPA (2006) Long Term 2 Enhanced Surface Water Treatment Rule. 40 CFR Parts 9, 141, and 142. Washington, D.C.

Hultquist, B. (2016) Basis for California's 12-10-10 Log Removal Requirements. Presented at the 20th Annual Water Reuse and Desalination Research Conference. Denver, CO.

Regli, S., Rose, J.B., Haas, C.N., and Gerba, C.P. (1991) Modeling the risk from Giardia and viruses in drinking water. *Journal American Water Works Association*, 83 (11), 76-84.

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H., and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

State Water Resources Control Board (2018). Regulations Related to Recycled Water. Updated October 1, 2018.

Protecting Water Quality in the Distribution System

ANSI/ASHRAE Standard 188-2015.Legionellosis: Risk Management for Building Water Systems. Atlanta, GA. American National Standards Institute (ANSI)/ASHRAE Standard 188-2015, 2015.

Falkinham, J.O., Pruden, A., and Edwards, M. (2015) Opportunistic premise plumbing pathogens: increasingly important pathogens in drinking water. *Pathogens*, 4, 373-386.

Jjemba, P., Weinrich, L., Cheng, W., Giraldo, E., and LeChevallier, M.W. (2010) Guidance Document on the Microbiological Quality and Biostability of Reclaimed Water Following Storage and Distribution (WRRF 05-02). WateReuse Research Foundation, Alexandria, VA.

Jjemba, P., Johnson, W., Bukhari, Z., and LeChevallier, M.W. (2015) Develop Best Management Practices to Control Potential Health Risks and Aesthetic Issues Associated with Reclaimed Water Storage and Distribution (WRRF 11-03). WateReuse Research Foundation, Alexandria, VA.

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H., and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

Thomure, T.M., Rock, C., Choi, C., Williams, D.S., Pepper, I., McLain, J., Lansey, K., and Rahman, R. (2014) Approaches to Maintaining Consistently High Quality Recycled Water in Storage and Distribution Systems. WateReuse Research Foundation, Alexandria, VA.

Weinrich, L.A., Jjemba, P.K., Giraldo, E., and LeChevallier, M.W. (2010) Implications of organic carbon in the deterioration of water quality in reclaimed water distribution systems. *Water Research*, 44, 5367-5375.

3 Treatment Selection and Crediting

This chapter addresses the key learning objectives for the Design Engineer and Regulator in the selection and crediting of treatment processes for ONWS. The specific learning objectives for this chapter are shown in Figure 6.

Chapter 3 Key Learning Objectives

DESIGN ENGINEER

- Application of treatment process validation and pathogen crediting
- Key treatment and monitoring concepts
- Treatment process design for compliance with LRTs
- Routine monitoring data collection requirements for ongoing LRT compliance

REGULATOR

- Existing pathogen crediting frameworks
- Treatment design and monitoring strategies for compliance with LRTs
- Evaluation of routine monitoring data for ongoing LRT compliance

Figure 6. Chapter 3 Key Learning Objectives.

Chapter 2 introduced log reduction targets – how they were developed and why they are important. This chapter focuses on how to design ONWS treatment systems that meet the required LRTs to protect public health. A key concept that is described is how pathogen log reduction "credit" is assigned to different unit processes that make up the treatment train. When seeking to comply with a given set of LRTs, a treatment train must be designed to include unit processes that – when summed together – achieve a pathogen log reduction value (LRV) equal to or greater than those LRTs. When selecting each unit process, the Design Engineer must consider at least two goals: 1) achieving the required LRTs, and 2) improving the overall water quality to deliver a product water ready for its intended use. There are many cases where both goals can be achieved at the same time with the same unit process.

This chapter introduces the concept of pathogen crediting for ONWS systems, and discusses each treatment process group in further detail. Figure 7 introduces the five key treatment process groups that are discussed: flow equalization, pre-treatment, biological treatment, filtration, and disinfection. For each process group, existing pathogen crediting frameworks are introduced, as well as details regarding water quality improvements accomplished by the process. The Design Engineer can use this chapter as a tool to help make decisions regarding what unit processes comprise an ONWS treatment train, how the system achieves the required LRTs, and how it produces water that meets overall water quality requirements.

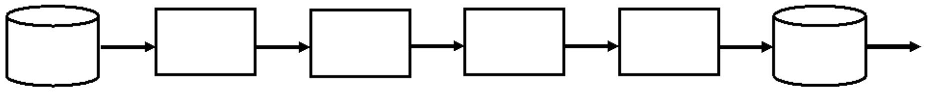


Figure 7. The Key Treatment Process Groups That Make Up an ONWS Treatment Train.

3.1 Pathogen Crediting

The concept of pathogen crediting originated with EPA's Surface Water Treatment Rule (SWTR). The SWTR and subsequent updates specify log reduction requirements for enteric virus and parasitic protozoa (i.e., *Giardia lamblia* and *Cryptosporidium*). To help facilities comply with these rules, EPA created guidance manuals that lay out approaches for demonstrating and receiving pathogen credit for various types of treatment, including membrane filtration, UV disinfection, and several types of chemical disinfection. Ultimate authority for enforcing the SWTR lies with the states, so in many cases states have produced their own documents to provide further guidance on pathogen crediting. Frameworks have also been adapted for alternate source waters, primarily treated wastewater for the purposes of potable and non-potable reuse. In many cases, the requirements from the SWTR guidance manuals are very similar to those used for recycled water, but in some cases the differences in source water quality have resulted in significant changes to the crediting approach.

The concept of pathogen crediting starts with considering how much reduction (i.e., physical removal and/or inactivation) a unit process achieves, and how to prove that reduction is occurring at all times. The extent of pathogen reduction is a function of the treatment mechanisms involved (e.g., physical removal in a membrane filter, DNA damage by UV irradiation) along with its design and operation. Ideally, each unit process is awarded pathogen credit for the levels it *actually* achieves. However, directly measuring pathogen reduction is limited by existing technologies, which typically need days to weeks to yield results. In lieu of direct pathogen measurements, surrogate monitoring methods are frequently used to provide a continuous evaluation of system performance (Figure 8). Examples include the use of turbidity to measure filter performance, or the use of a disinfectant "CT" dose to quantify the degree of inactivation.

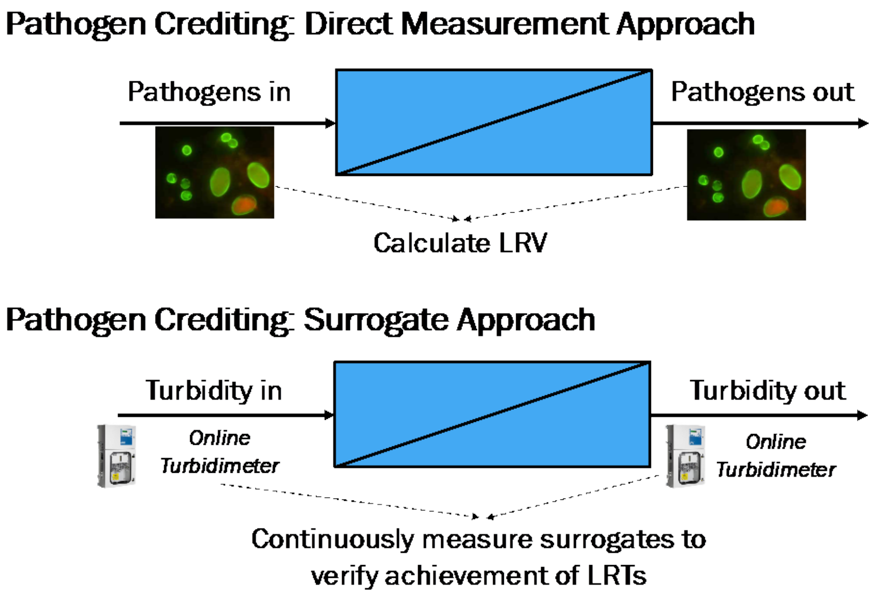


Figure 8. Pathogen Crediting Through a Unit Process Typically Relies on Surrogate Monitoring. Surrogates often underestimate the actual level of pathogen reduction occurring but are selected for their real-time measurement capabilities over direct pathogen measurements.

To quantify pathogen reduction and assign specific log reduction credit through a treatment process, Regulators often rely on prior validation or challenge studies using actual pathogens or microbial indicators. Validation studies often consist of pathogen reduction tests conducted over a range of water quality conditions. Changes in water quality parameters (such as turbidity) are measured at the same time in order to identify surrogates whose reduction can be tied to pathogen reduction. Based on these findings, pathogen crediting criteria are developed using the surrogate parameter, typically with conservative safety factors included. These criteria may describe the water quality characteristics or operating requirements that achieve specific pathogen log reduction levels. The pathogen reduction and associated operating conditions can then be used to define pathogen reduction credit for the unit process.

Existing pathogen crediting frameworks cover most conditions that are relevant for ONWS systems, but not all. The Design Engineer may decide that it is desirable and feasible to create a new crediting framework for a unit process, either through product-specific or site-specific validation. Although this Guidance Manual does not describe the specific activities that would be required to achieve such a validation, the existing frameworks described in the next sections give a general indication of what the validation would need to accomplish. **Generally speaking, utilizing frameworks already developed by regulatory agencies is the most efficient way to move forward with implementation of systems that comply with pathogen LRTs.** Table 4 shows a summary of some of the existing validation frameworks. While the pathogen LRTs have been specified for protozoa, there are differences in the effectiveness of unit processes in the reduction of the two historically regulated protozoa, *Giardia* and *Cryptosporidium*. Consequently, existing frameworks distinguish between virus, *Giardia*, and *Cryptosporidium,* which are designated as V/G/C in Table 4. As implementation of ONWS becomes more widespread and proven with robust data sets, pathogen crediting frameworks may be further refined or developed for both common and alternative technologies specific to the source water and end use.

Table 4. Summary of Selected Existing Validation Frameworks for Determining Pathogen Reduction Credit for Virus (V), the Two Regulated Protozoa – *Giardia* (G) and *Cryptosporidium* (C), and Bacteria (B).

Treatment Category	Application	Unit Process	Applicable Pathogens	References
EPA Disinfection	Surface Water	Free Chlorine	V / G	a, b, c, d, e, f
		Chloramine	V / G	
		Chlorine Dioxide	V / G / C	
		Ozone	V / G / C	
		UV	V / G / C	
EPA Filtration	Surface Water	Membrane Filtration	G / C	d, f, g
		Reverse Osmosis	V / G / C / B	
		Bag and Cartridge Filters	G / C	
NWRI UV Disinfection	Potable Water & Recycled Water	UV	V / G / C	h
Australian MBR	Recycled Water	MBR	V / G / C / B	i
Australia Chlorine	Recycled Water	Free Chlorine	V / B	j

A. U.S. EPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.
B. U.S. EPA (1999) Disinfection Profiling and Benchmarking Guidance Manual.
C. U.S. EPA (1999) Alternative Disinfectants and Oxidants Guidance Manual.
D. U.S. EPA (2006) Long Term 2 Enhanced Surface Water Treatment Rule.
E. U.S. EPA (2006) Ultraviolet Disinfection Guidance Manual for the Final Long-Term 2 Enhanced Surface Water Treatment Rule.
F. U.S. EPA (2010) Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual.
G. U.S. EPA (2005) Membrane Filtration Guidance Manual.
H. NWRI (2012) Ultraviolet Disinfection: Guidelines for Drinking Water and Water Reuse, 3rd Edition.
I. WaterSecure (2017) Membrane bio-reactor: WaterVal validation protocol. Australian WaterSecure Innovations, Brisbane, Australia.
J. WaterSecure (2017) Chlorine Disinfection: WaterVal validation protocol. Australian WaterSecure Innovations. Brisbane, Australia.

Pursuing Pathogen Credits in the Absence of an Existing Regulatory Framework

Existing pathogen crediting frameworks exist for many unit processes through rigorous testing and evaluation by organizations such as the U.S. EPA, the National Water Research Institute, and Australian WaterVal. Nevertheless, ONWS Project Teams could seek to develop new pathogen crediting frameworks for processes that do not currently have frameworks (including engineered treatment wetlands or novel disinfection technologies). The level of effort to create a new crediting framework may be a significant investment in terms of both cost and time, and so should be carefully considered by both the Design Engineer and System Owner before pursuing. In some cases, the costs of conducting microbial challenge studies to characterize process performance may be significantly greater than the cost of the technology itself (e.g., a UV reactor). **The decision to pursue credits outside of an existing framework should therefore be made jointly by both the Design Engineer and System Owner, in frequent communication with the Regulator who will ultimately decide what level of effort is needed to assign credit to a novel process or application.**

Pathogen credits for each unit process are assigned based on the decision to either (a) use an existing crediting framework, or (b) develop and conduct a site-specific validation. Alternatively, a treatment process can be used to meet general water quality and/or operational benefits, without receiving pathogen credit. The following sections focus on the five key process groups (Figure 7) and describe their benefits for improving water quality and/or meeting the pathogen LRTs.

Bacterial Crediting

One challenge implementing the LRT framework is that there are not existing crediting frameworks for bacteria. Historically, control of bacteria has been demonstrated through end-point monitoring, i.e., measuring treated effluents to demonstrate the absence of coliform. Under such a framework, it is not necessary to measure the performance of the treatment processes and assign log reduction credits. Consequently, crediting frameworks for bacteria do not exist. This poses a challenge to the implementation of the ONWS LRT framework for bacterial control. In the absence of such guidance, two potential approaches exist for ensuring control of pathogenic bacteria. The first is to continue the historical model and require routine end-point monitoring of total coliform bacteria to demonstrate that the levels are at or below the limit of detection (e.g., no more than 2.2 MPN/100 mL). This strategy departs, however, from the intention to replace end-point monitoring with online verification of process performance.

Alternatively, ONWS programs could decide to assign bacterial reduction credits based on an understanding of pathogen removal and inactivation through the various unit processes. The Guidance Manual proposes a number of potential bacterial crediting frameworks for unit processes where this relationship might be made. Additional research efforts to further develop and evaluate bacterial crediting frameworks are recommended.

3.2 Flow Equalization

> DESIGN ENGINEER
>
> The **Design Engineer** should give careful consideration to source water quality and production variability to determine if equalization is needed and the optimal storage volume.

A significant challenge for both the Design Engineer and Operator is source water variability. ONWS source waters may vary significantly – sometimes even over the course of a day – especially if the water is being collected from multiple sources. Furthermore, the supply of source water and demand for recycled water is often intermittent, leading to additional considerations for both treatment and storage. The Design Engineer should give careful consideration to these source water quality and production patterns, as they help determine the flow equalization required to limit impacts on sizing and performance of unit treatment processes (Figure 9). ONWS can benefit from flow equalization at both the raw and treated water sides of the treatment train; the benefits and considerations for both are discussed below.

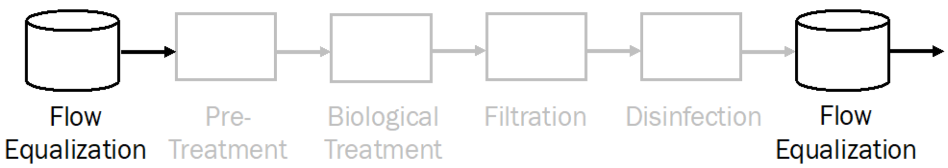


Figure 9. ONWS Systems Can Benefit from Flow Equalization at Both the Raw and Treated Water Sides.

Source Water Variability

Both the type of building and the type of source water(s) determines the quality, quantity, and timing of water available for treatment. For example, blackwater and graywater in a commercial or residential building typically have a much more predictable and consistent production pattern than rainwater or stormwater. The type of building also has a significant impact on the patterns of source water generation. For example, a commercial building is likely to see consistent production of blackwater and graywater during the day on weekdays, with much less generation in the evening and on weekends; however, a residential building is likely to see consistent production of blackwater and graywater in the morning and evening during the week and throughout the day on weekends, with much less generation during the weekday. A mixed-use building that is both commercial and residential represents some combination of these source water production patterns.

The source water production pattern also impacts the variability in water quality. For example, source water quality (i.e., biological oxygen demand (BOD), total suspended solids (TSS), turbidity, ammonia, pathogens) of blackwater in a commercial building may spike during mid-morning or mid-afternoon while similar spikes may occur in a residential building during the morning (prior to work hours) and evening (after work hours) when the buildings are occupied.

Table 5 provides typical ranges of water quality values that may be encountered for different types of source waters. This information can be used as a general guide for what to expect from different source waters, but there is no replacement for site-specific characterization of the ONWS source waters. Unfortunately, it is often not possible to collect source water samples, particularly for new buildings that are in planning, under construction, or that have not yet been occupied. The lack of site-specific water quality data – including knowledge of source water strength and variability – poses a challenge for the design of ONWS systems. If possible, it is recommended that site-specific water quality measurements be taken from the actual building or similar type of building to quantify the range and variability of each key design parameter. While beyond the scope of this document, the Design Engineer should also give special considerations to collection, treatment, and regulatory compliance if there is an industrial contribution to the source water (i.e., laboratory, medical facility, etc.).

Table 5. Typical Ranges of Source Water Quality for Various Sources.

Type of Source Water	Total Coliform (CFU/100ml) [1]	BOD (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH	Ammonia (mg/l as N)
Rainwater	10^2 - 10^3	<15	20 - 50	10 - 30	No Data	N/A
Stormwater	10^2 - 10^5	<40	100 - 500	No Data	No Data	No Data
Graywater	10^4 - 10^7	100 - 300	100 - 300	20 - 200	6 - 9	3 - 10
Blackwater	10^8 - 10^{10}	700 - 1,000	300 - 600	No Data	6 - 9	50 - 150

1. CFU/100ml is colony forming units per 100 milliliters.

Equalization Design

Due to the variability in source water production and user demand patterns, ONWS systems typically require some degree of flow equalization, either of (a) the source water before treatment, (b) the supply water after treatment, or (c) both the source and supply water. Equalization helps mitigate the extreme fluctuations in both flow and quality that may cause challenges for the unit treatment processes. Most unit treatment processes have an optimal operating range (minimum and maximum values) where they reliably meet the design and performance requirements and remain online. Additionally, unit treatment processes perform optimally when they run at consistent conditions with minimal adjustments over time. The Design Engineer should attempt to find a balance between the increased footprint of flow equalization with the optimal operating range of the unit treatment processes to ensure both a reliable treatment system and a reliable supply of water for the end use.

A simplified example in Figure 10 demonstrates the concept of flow equalization. In both scenarios, a total of 10,000 gallons of source water is collected over the course of a day, and the building demand is evenly distributed over the day. In the scenario on the left, source water is generated for 12 hours per day (between 0600 and 1800 hours), requiring 5,000 gallons of storage to meet the continuous building demands when source water is not being generated. In the scenario on the right, source water is generated 18 hours per day (between 0200 and 2000 hours), requiring 2,500 gallons of storage. **When source water is generated over a shorter time period, a larger storage volume is required to meet a constant demand.** The storage volume equalizes the variable influent flow to ensure that demands can be met. If ONWS systems experience variability in both influent flow and treated water demand, flow equalization may be needed at both the beginning and end of a treatment train.

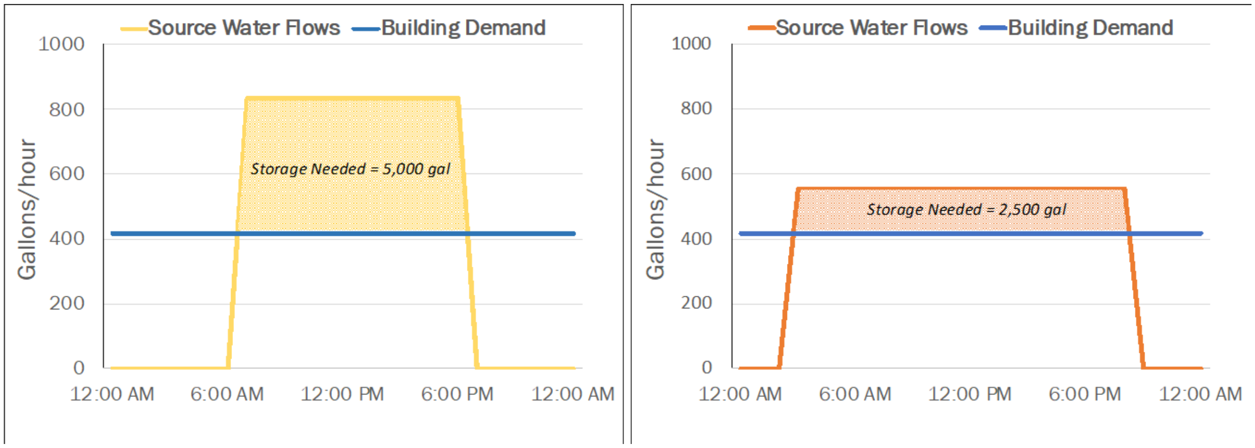


Figure 10. Examples of How Required Storage Volumes Can Be Determined to Equalize Influent Flows and Meet Building Demands.

In the absence of equalization, the unit processes must be sized to handle peak flows resulting in more expensive treatment systems. Equalization allows treatment processes to be sized for a more optimal range, providing benefits both for cost and performance. Multiple processes – including both biological and membrane processes – perform better when receiving a constant or near-constant flow rate.

Treated water storage may also be beneficial if spikes in building demands are significantly higher than the maximum production rate of the treatment train. Storage also offers operational benefits including continued treated water distribution during temporary treatment train shutdowns and a location for blending and equalization for a temporary potable water supply. The Design Engineer should consider these contingencies during design in order to make the ONWS system operator-friendly and reliable.

Summary of Flow Equalization

Table 6 provides information comparing the two types of flow equalization described in this chapter.

Table 6. Summary of Considerations for Equalization.

Treatment Process	Pathogen Credit	Pros	Cons
Source water equalization	0 LRV	• Equalizes influent flows and water quality. • Minimizes downstream process sizing. • Promotes effective downstream treatment.	• Requires large footprint
Treated water equalization	0 LRV	• Equalizes effluent flow and water quality. • Minimizes upstream process sizing. • Allows for maintenance activity while maintaining access to recycled water.	• Requires large footprint

3.3 Pretreatment

The first unit treatment process in many ONWS treatment facilities is pretreatment, with the primary goal of removing coarse materials prior to downstream treatment processes (Figure 11). If not removed, these coarse materials could potentially damage or plug downstream equipment and reduce the effectiveness of the treatment.

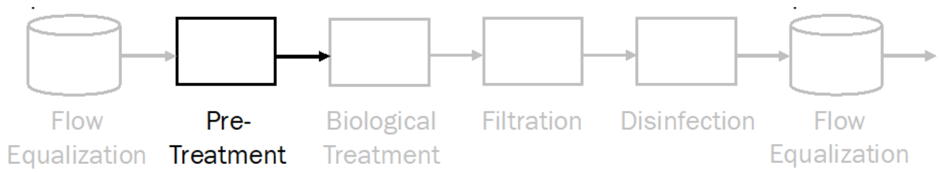


Figure 11. Pretreatment in ONWS Systems Typically Consists of Screens to Prevent the Passage of Coarse Particulate Matter Into Downstream Processes.

> DESIGN ENGINEER
>
> The **Design Engineer** should evaluate source water quality to determine the size, or combination of sizes, of pretreatment screen to select.

One pretreatment technology commonly used is a screen, a device with openings of a uniform size used to retain solids. Screen types include both coarse and fine screens. Coarse screens are designed to handle larger solids and debris, easily separating them from the process flow and collecting them for later disposal. Fine screens are capable of removing smaller solids and debris, but could become clogged if larger solids remain in the water. Both types of screens can be designed for self-cleaning, allowing the process to run autonomously and minimize down time due to maintenance. **Self-cleaning screens are ideal for ONWS systems, and the residual waste can typically be discharged directly to the sewer to reduce the need for handling and offsite disposal.**

Another pretreatment alternative is a vortex filter, commonly used for initial treatment of stormwater and harvested rainwater. Vortex filters work by creating hydraulic conditions that separate solids (and hydrocarbons, depending on the type of filter) from the main process water, collecting the waste for later removal. The solids removal is done manually, and therefore requires regular maintenance that usually consists of cleaning a filter element.

Summary of Pretreatment

Table 7 provides information comparing the two types of pretreatment technologies described in this chapter.

Table 7. Summary of Considerations for Pretreatment Screening.

Treatment Process	Pathogen Credit	Pros	Cons
Coarse Screen	0 LRV	• Removes large solids and debris. • Robust removal of solids and debris.	• Does not remove finer solids, allowing them to continue downstream.
Fine Screen	0 LRV	• Improves water quality through decreased TSS and turbidity.	• May not be able to handle larger solids/debris, potentially causing additional maintenance.
Vortex Filter	0 LRV	• Removes large solids, debris, and hydrocarbons.	• Typically requires manual filter cleaning.

3.4 Biological Treatment

Biological treatment, also known as secondary treatment in wastewater applications, is an essential step and the workhorse of ONWS systems for treating blackwater and graywater[3]. Biological treatment steps reduce biological oxygen demand, suspended solids, dissolved organic matter, nutrients, and pathogens. Typically, biological treatment for ONWS employs aerobic processes including suspended growth, attached growth, and hybrid suspended/attached growth. These aerobic processes are incorporated into biological treatment technologies that include a range of technologies from membrane bioreactors (MBR) and conventional activated sludge to natural systems including engineered treatment wetlands (Figure 12).

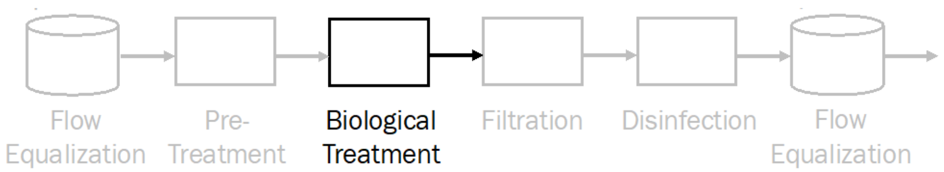


Figure 12. Biological Treatment is Typically Required for ONWS Source Waters That Are High in Organic Loading (e.g., blackwater and graywater).

[3] Technologies such as granular activated carbon (GAC) can also be used to reduce organic concentrations in an ONWS source water. GAC is typically used, however, to polish waters already low in organic concentrations. GAC is not recommended to serve as the principal organics barrier when treating a source water with high organic concentrations, including graywater and blackwater.

General Biological Treatment Objectives

With any type of biological treatment, there are several key treatment objectives that should be considered by the Design Engineer:

BOD, TSS, and Turbidity

Typical biological treatment processes remove 85-95% of the organic matter measured as BOD and TSS (which is also a major contributor to turbidity) in blackwater. The EPA's 2012 Guidelines for Water Reuse suggested that recycled water suitable for use in applications similar to ONWS should have BOD ≤ 10 mg/L and turbidity ≤ 2 NTU. Other references suggest that the BOD and TSS should not exceed an average of 10 mg/L in order to minimize microbial regrowth in the ONWS distribution system (see the section below on distribution system considerations for more information). The Design Engineer should consider selecting a reliable biological treatment system to meet or exceed the BOD, turbidity, and TSS treatment requirements because they can have a significant impact on the design, cost, and performance of downstream treatment processes.

Ammonia

Ammonia is another water quality parameter that should be considered when designing and selecting a biological treatment process. Typical values of ammonia in blackwater may range from 50-150 mg/L. Biological treatment using nitrification is the primary method used for reducing ammonia in wastewater, which requires aerobic conditions and appropriately designed solids retention times (SRT). Reducing the ammonia concentration can be an important treatment objective when considering downstream disinfection options and distribution system management. For example, ammonia concentrations should be reduced to less than 1 mg/L for reliable disinfection with free chlorine; otherwise, the ammonia reacts with chlorine to form chloramine – a weaker oxidant. This concept is further discussed in the disinfection section. Excess ammonia in the ONWS product water can also lead to the growth of bacteria in the distribution system – an unwanted scenario that is further discussed in the distribution system management section below.

Pathogen Reduction

In general, the degree of pathogen removal or inactivation through biological processes is not well understood. Consequently, most biological processes do not receive pathogen reduction credit under existing frameworks.

Membrane Bioreactors

One advantage of MBR compared to other forms of biological treatment is that it benefits from an existing framework for pathogen crediting. MBRs combine suspended growth biological treatment with an integrated membrane system to provide enhanced organics and suspended solids removal (Figure 13). One of the primary advantages of this integration is that it removes the need for a separate gravity sedimentation, or clarification, process, which reduces the overall footprint requirements. This makes MBRs attractive for sites with limited footprints, a typical scenario for ONWS systems.

Figure 13. Schematic of a Membrane Bioreactor.
Courtesy of Suez Water Technologies & Solutions.

The biological treatment portion of an MBR is a suspended growth system with a high mixed liquor suspended solids (MLSS) concentration, and the membrane filter is typically a micro-filtration (MF, ~0.1 μm pore size) or ultra-filtration (UF, ~0.01 μm pore size) membrane. These systems have several pathogen reduction mechanisms including size exclusion, adsorption, and biodegradation. There are several sources of adsorption sites in the system, including the suspended solids within the activated sludge and the cake layer that forms on the membrane as it fouls. Predation by larger organisms has also been shown to reduce the concentrations of some smaller pathogens. Table 8 outlines key considerations for MBR design.

Table 8. Key Design Considerations for an MBR.

MBR Design Considerations	MBR Performance Considerations
Physical wastewater constituents	If not removed with pretreatment, physical constituents such as high TSS, hair, fibrous material, and other inert solids may build up on the membrane surface which could impact performance and damage membranes.
Chemical wastewater constituents	Constituents such as high alkalinity, soluble iron, oil and grease, surfactants, and oxidants may cause accelerated membrane fouling, foaming, and attacks on certain types of membrane materials.
Biological wastewater constituents	Dissolved and colloidal organic matter and extracellular polymeric substances may clog membrane pores and diminish performance.
Biological waste streams or sludge	An important parameter for process control/operation, but handling (collection and treatment) and disposal options should be considered.
Bioreactor suspended solids concentrations	MLSS ranges of 8,000 to 12,000 mg/L are typical.
Type of membrane including pore size and materials of construction	Typical membranes are either microfiltration or ultrafiltration with pore sizes ranging from 0.1 µm to 0.01 µm.
Membrane flux rate	Membrane flux rate is the rate of water transfer through the membrane surface and impacts the overall process economics, operating conditions, and number of membranes.
Membrane life/warranty	The replacement frequency and warranty on the membranes should be considered for estimating operating and maintenance costs and requirements.
Solids and hydraulic retention times	Solids Retention Time and Hydraulic Retention Time are critical factors for design of the biological reactor and impact peak flow rates that can be accommodated.
Membrane fouling control and cleaning	In addition to air scour, backflushing and maintenance cleaning should be considered to minimize membrane fouling, increased pressure loss, and reduction in flux rate.
Air supply/aeration	Proper design of the aeration system should be considered to sustain the biological process and clean the membranes.
Pretreatment	Fine screens should be considered as membranes are sensitive to damage by inert solids such as plastics, rags, oils, fats, and hair.

Pathogen Crediting for Membrane Bioreactors

An additional benefit of MBRs is that there is an existing framework that has been accepted for assigning pathogen reduction credits – the Australian WaterVal Validation Protocol (WaterSecure 2017a). The Australian MBR validation protocol specifies conditions that allow for crediting without requiring site-specific validation. Sites can receive the default "Tier 1" pathogen credits (Table 9) if operated within a specified range of operating conditions referred to as the *operating envelope* (Table 10). Field verification must be done to confirm that the system is operating within the Tier 1 operating envelope, which entails operating and monitoring the system to demonstrate that all of the required performance and water quality metrics are met. No site-specific pathogen testing is required.

Table 9. Default MBR Pathogen LRVs for the Australian WaterVal MBR Tier 1 Validation Protocol.
WaterSecure 2017a.

Pathogen Type	Default LRV
Virus	1.5
Protozoa	2
Bacteria	4

In addition to initial field verification, systems must perform continuous indirect integrity monitoring on an ongoing basis by demonstrating that the system always has effluent turbidity $\leq$ 0.2 NTU. All Tier 1 operating envelope parameters also need to be continuously monitored, including MLSS, hydraulic retention time (HRT), membrane flux, permeability, and temperature.

Table 10. Summary of MBR Operating Envelope for Tier 1 Default LRV Credits.
WaterSecure 2017a.

Parameter	Units	Minimum	Maximum
Bioreactor pH	pH units	6	8
Bioreactor dissolved oxygen	mg/L	1	7
Bioreactor temperature	C	16	30
Solids retention time	d	11	–
Hydraulic retention time	h	6	–
MLSS	g/L	3	–
Transmembrane pressure	kPa	3	–
Membrane flux	$L/m^2/h$	–	30
Turbidity	NTU	–	0.2

Engineered Treatment Wetlands

MBRs have numerous advantages for ONWS systems including both small footprint and the ability to obtain pathogen log reduction credit. On the other hand, an MBR is a complex process – with both biological and mechanical elements – that has significant energy demands. Engineered treatment wetlands offer an alternative to the higher-technology MBR option with a different set of advantages and disadvantages. Wetlands typically require a larger footprint to achieve similar levels of treatment (e.g., BOD, TSS, and total organic carbon (TOC) destruction), and so may be less desirable in space-constrained settings. However, many sites that utilize wetlands take advantage of their natural aesthetics to enhance the visual quality of the building and to serve as a visual public reminder of the ONWS system. In many cases, wetlands can have significantly lower energy requirements than MBR systems.

Pathogen Crediting for Engineered Treatment Wetlands

While numerous research studies have been undertaken to evaluate pathogen reduction in wetlands, no existing frameworks are available for pathogen reduction crediting. Site-specific studies could be undertaken to correlate pathogen reduction with surrogate parameters (e.g., BOD, TSS, TOC, etc.). It should be noted that there are not established frameworks for crediting biological treatment in municipal wastewater settings. Consequently, there are not as many precedents or exemplars for such a validation study. Additional recommendations for the validation of unit processes can be found in the ONWS Expert Panel report, including the use of challenge or spiking studies to quantify reduction through the process. Such an approach could be applied to quantify wetland treatment within a defined operating envelope, as was developed for MBRs under the Australian validation framework. Nevertheless, engineered treatment wetlands can provide a number of additional benefits besides pathogen reduction (e.g., reduction in BOD and suspended solids), making the water better suited for log reduction through downstream processes.

Summary of Biological Treatment

Table 11 provides information comparing the two types of biological treatment technologies described in this chapter.

Table 11. Summary of Considerations for Biological Treatment.

Treatment Process	Pathogen Credit	Pros	Cons
Membrane Bioreactors	1.5 virus 2 protozoa 4 bacteria LRV	• Small footprint. • High-quality filtered effluent low in BOD, TSS, and turbidity. • Pathogen crediting framework available.	• Higher energy requirements. • Complex operations.
Engineered Treatment Wetlands	0 LRV	• Lower energy requirements. • High degree of BOD and TSS reduction • Aesthetics.	• Large footprint. • No existing pathogen crediting framework. • Lower effluent quality than MBR.

3.5 Filtration

Filtration is the removal of suspended and colloidial particulate matter by a physical process. Typical treatment technologies include membrane filters (i.e., microfiltration and ultra-filtration), cartridge filters, and reverse osmosis (Figure 14).

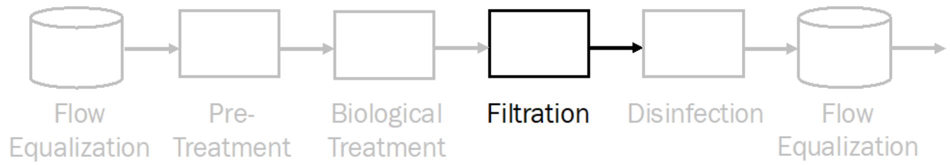


Figure 14. Filtration Is Used to Remove Particulate Matter (including pathogens) and Prepare the Filtered Water for Disinfection.

General Filtration Objectives

The Design Engineer should consider the water quality entering a filtration system, whether it be effluent from an upstream biological treatment process, or raw source water (e.g., stormwater). Selecting and sizing a filtration system will depend on how the influent water quality compares to the desired water quality for the downstream disinfection treatment process. Suspended solids, size distribution of particulate matter, and turbidity are important design parameters.

TSS and Turbidity

Filtration is needed for most onsite source waters as a pathogen removal process and/or pretreatment for disinfection. Even for systems using biological treatment processes that provide significant removal of TSS, filtration is generally still needed to provide another barrier against TSS and turbidity. The Design Engineer should consider selecting a reliable filtration system to meet or exceed turbidity requirements due to the significant impact on the design, cost, and performance of downstream disinfection, overall water quality, regulatory compliance, and operations and maintenance.

Pathogen Removal

Filtration has the dual benefit of both 1) removing some pathogens, and 2) removing particulates that may shield pathogens from effective disinfection downstream. **Furthermore, several filtration technologies have existing regulatory frameworks for pathogen crediting** as discussed below in the sections on specific filtration technologies

Membrane Filtration

Membrane filtration is a pressure-driven process that utilizes a membrane to sieve and remove particles and macromolecules. The two main forms of membrane filtration are microfiltration, or MF (with pore sizes around 0.1 μm) and ultrafiltration, or UF (with pore sizes around 0.01 μm). Membrane filters can typically provide higher degrees of particulate removal than media filters, leading to lower effluent turbidities. The pore sizes of membrane filters are also small enough to physically exclude the larger-sized pathogens from passing into the effluent. Given that membrane processes are pressure-driven, pumping is typically required for membrane filter operation. The larger energy requirements are offset by more compact footprints than other forms of filtration, such as granular media filtration.

Pathogen Crediting for Membrane Filtration

EPA's Membrane Filtration Guidance Manual provides a framework for granting protozoa removal credits to MF and UF. Although this framework is for drinking water, the concepts could be applied to ONWS systems. Regulators have used this framework for pathogen crediting of membranes for municipal-scale potable reuse systems.

Current practice under the drinking water framework is to award pathogen credit – 0 log removal credit for virus, 4-log removal credit for *Giardia*, and 4-log removal credit for *Cryptosporidium* – to systems that can demonstrate their ability to 1) detect a breach of 3 μm or larger with a membrane integrity test, and 2) meet the continuous turbidity requirements. A breach of 3 μm or greater is relevant because it represents the size of *Cryptosporidium* oocysts, the smaller of the two protozoan pathogens. Because bacteria may be significantly smaller than *Cryptosporidium* oocysts, the direct integrity tests may not provide a conservative representation of bacterial removal through MF/UF. As a result, bacteria removal credit based on protozoa removal is not recommended for MF/UF systems. Additional research in this area is recommended to develop a bacterial crediting framework.

Two types of ongoing monitoring are required: direct and indirect integrity testing. EPA defines a direct integrity test as "a physical test applied to a membrane unit in order to identify and isolate integrity breaches." The three requirements for a direct integrity test are as follows:

- Must be responsive to integrity breach on the order of 3 μm (or less).
- Must verify LRV equal to or greater than the removal credit awarded.
- Must be conducted on each membrane unit no less than once per day that the process is operational.

Direct integrity testing is typically accomplished with a pressure decay test (PDT), in which pressure is applied to membrane units and the subsequent loss in pressure is monitored over time. The rate of pressure loss can be related to the size of holes in the membrane and used to identify significant breaches in the system. In intact systems, the loss of pressure occurs slowly; this rate increases as the system experiences more breaches. As part of the membrane validation process, control limits must be developed for PDTs (or an alternate direct integrity test). These limits indicate the pressure decay rate above which there is a breach of 3 μm or greater. If the PDT on a membrane unit fails to meet this limit, that unit must be taken offline. Because direct integrity testing requires membrane units to be taken offline, it is generally done no more frequently than once per day.

The size of the membrane breach that can be detected is inversely proportional to the amount of pressure required – that is, higher pressures are needed to detect smaller holes. The amount of pressure needed to detect a virus-sized integrity breach is beyond the capacity of any existing MF/UF units to withstand; therefore, although virus removal may be documented during validation testing, it cannot be verified on an ongoing basis and so is generally not credited.

In addition to periodic direct integrity testing, continuous indirect integrity testing is also required. This consists of monitoring an aspect of filtrate water quality that is reflective of the removal of particulate matter: typically, this is accomplished through the measurement of effluent turbidity. 'Continuous' monitoring is defined as measuring at least once every 15 minutes. If the turbidity is above 0.15 NTU for greater than 15 minutes, a direct integrity test must be triggered. Monthly reporting of all monitoring results that triggered direct integrity testing, along with the corrective action taken in each case, is required.

Reverse Osmosis

Reverse osmosis (RO) is a membrane process that removes dissolved constituents by forcing water through a semi-permeable membrane. The process creates a high-quality product stream, or permeate, by effectively removing both inorganic and organic compounds, color, and odor-causing compounds. For many ONWS applications, this level of treatment is beyond what is needed for non-potable end uses, particularly if the source water does not have high levels of salts, organics, and color. Due to the requirement for high feed pressures (>100 psi), RO is also one of the most energy-intensive processes. Furthermore, it requires significant pretreatment, typically membrane filtration, in order to protect the RO membranes. The Design Engineer should also consider that RO produces a waste brine stream that is typically 15-25% of the volume of water treated. The management of the brine streams may also be a significant constraint; sites that cannot discharge the brine back into the sanitary sewer will need to find alternative disposal options. All options can come with challenges: discharging brine to the sanitary sewer could result in substantial costs associated with the high BOD and TSS load that is typical of brine wastes, and alternative disposal options may require additional capital and O&M investment.

Aesthetics and Color Removal

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An important consideration for **Design Engineers** that is not covered in detail in the Guidance Manual is aesthetics, including the removal of color. While not a direct public health concern, the presence of color may lead to issues with public acceptance of ONWS systems. Multiple treatment processes can be used – alone or in combination – to remove color. Typically, color will be more of an issue with source waters with higher organic concentrations, e.g., blackwater and graywater. The use of a biological process in the train provides the first barrier against color, and can be further reduced through the use of a disinfection oxidant such as ozone or chlorine. Filtration technologies such as RO and GAC will also provide further polishing and color removal.

Pathogen Crediting for Reverse Osmosis

The EPA has developed a framework for RO pathogen crediting in drinking water applications, and similar frameworks have been developed by state regulators for potable reuse applications. These frameworks provide RO systems with pathogen removal credits equal to the removal of a continuously measured surrogate parameter, such as electrical conductivity (EC) or total organic carbon (TOC). Online monitors are used in both the influent and effluent to continuously quantify removals, with the assumption that pathogen removal will be no less than the reduction in EC or TOC. TOC monitors are more expensive than conductivity meters, but have a higher sensitivity than EC, allowing for higher log reduction to be demonstrated. In addition to measuring removal of a surrogate parameter, RO systems must establish control limits that define the acceptable operating range; when operation crosses outside the control limits, corrective actions must be taken.

Compared to membrane filtration (either MF or UF), RO has been shown to provide greater rejection of pathogens. Unfortunately, because there is not currently a direct integrity test for RO that can demonstrate this high rejection on an ongoing basis, RO systems receive less protozoa credit than MF/UF systems. However, the advantage of RO systems over MF/UF systems is that RO is eligible for removal credit for all pathogen groups – including virus. Typical pathogen credit for RO systems is 1-log virus, Giardia, and Cryptosporidium (V/G/C) when using EC as the surrogate monitor and approximately 2-log for V/G/C when using TOC as the surrogate monitor. Log removal for bacteria should be conservatively similar to virus for purposes of granting credit in an ONWS system.

Cartridge Filtration

Like membrane filters, cartridge filters are pressure-driven separation devices that remove large particles typically using replaceable filter elements housed in pressure vessels. When the water flows through the filter within the vessel, particles collect on the filter surface leading to a drop in water pressure. When the pressure drop reaches a specified level, the filter is replaced. This aspect differentiates cartridge filters from membrane filters in that the membrane filters periodically undergo backwash cycles to flush the particles off of the membrane surface. Consequently, membrane filters can be used for multiple cycles (typically multiple years) before replacement, whereas cartridge filters require more frequent replacement.

Pathogen Crediting for Cartridge Filters

Under EPA's Long Term 2 Enhanced Surface Water Treatment Rule (LT2), 2.0- to 2.5-log *Cryptosporidium* credit can be achieved with cartridge filtration. To receive this credit, challenge testing must be undertaken (typically on a product-specific basis) in compliance with LT2 requirements to demonstrate effective removal of particles larger than 1 micrometer. All filters must demonstrate a minimum of 3.0-log removal through challenge testing. Subsequently, a conservative 2.0-log credit is assigned to individual cartridge filters and 2.5-log credit for cartridge filters in series. Given that *Giardia* cysts are larger than *Cryptosporidium* oocysts, the same log removal credit can conservatively be assumed to apply for *Giardia* as well. Effluent turbidity requirements are not included in LT2 if the cartridge filters are installed downstream of a primary filter. In ONWS settings, however, the cartridge filter will frequently serve as the primary (and exclusive) form of filtration, in which case effluent turbidity requirements should be specified. In drinking water scenarios, effluent turbidity requirements specify that 95% of the values be less than 1 NTU with no values exceeding 5 NTU (e.g., EPA Surface Water Treatment Rule guidance on cartridge filter performance).

Summary of Filtration

Table 12 provides information comparing the three types of filtration technologies described in this chapter.

Table 12. Summary of Considerations for Filtration.

Treatment Process	Pathogen Credit	Pros	Cons
Membrane Filtration	4-log Protozoa	• Reliable, high degree of turbidity removal. • Existing pathogen crediting framework. • Smaller footprint.	• Higher energy use. • Membrane replacement is required. • Special cleaning is occasionally required due to membrane fouling.
Reverse Osmosis	Up to: 2-log Virus 2-log Protozoa 2-log Bacteria[1]	• Complete turbidity removal. • Existing pathogen crediting framework. • Smaller footprint.	• Highest energy use. • Membrane replacement is required. • Special cleaning is occasionally required due to membrane fouling. • A concentrate waste stream is created that requires proper disposal and decreases the amount of water produced.
Cartridge Filtration	2-log Protozoa	• Easy operation. • Lowest energy usage.	• Requires more frequent replacement than membrane filters. • Lower pathogen credits.

1: Pathogen log removal credit depends on surrogate parameter.

3.6 Disinfection

Disinfection refers to the destruction and/or inactivation of pathogenic microorganisms by exposure to a chemical agent or physical process. In the context of water treatment, this is generally accomplished in flow-through reactors where a disinfectant is continuously being added. The extent of disinfection achieved by a given process is a function of the susceptibility of a particular pathogen to a disinfectant, the concentration to which it is exposed, and the duration of the exposure. The most commonly used framework for disinfection is the CT framework where CT refers to the product of the disinfectant residual concentration (C) and the contact time (T). The EPA has developed CT tables for several disinfectants and pathogen types, which are discussed in the sections below. These tables can be used to identify the level of treatment that must be provided to achieve a specific log reduction for different pathogen groups (Figure 15).

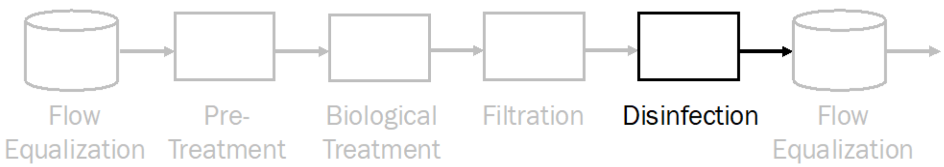


Figure 15. Disinfection Is Used to Inactivate Pathogens and Attain the Minimum Log Reduction Targets.

Chlorine Disinfection

Chlorine is a disinfectant that is commonly used in drinking water, non-potable reuse, and potable reuse treatment. Multiple forms of chlorine are used, though the most common forms are free chlorine and combined chlorine. The mechanism of pathogen inactivation is the oxidation and destruction of critical biological structures including the genome, proteins, and structural elements of microorganisms. Protozoa are more resistant to both free and combined chlorine than viruses, meaning that longer contact times are typically needed for protozoa disinfection. Given site constraints in ONWS settings, large disinfection contactors are typically not feasible, so chlorine disinfection is often limited to virus control.

Chlorine CT Framework

Chlorine disinfection crediting relies on the CT framework. The two key design and crediting parameters are therefore the chlorine residual concentration (C) and the contact time provided by the chlorine contactor (T) at the point of compliance. Determining the CT needed to achieve a certain level of virus disinfection credit depends on several factors:

- The EPA free chlorine CT tables provide CT values needed for varying levels of virus and *Giardia* inactivation as a function of pH and temperature (EPA 1991). These tables were developed for surface water, and so are appropriate for rainwater and stormwater which in general have lower levels of organics and low turbidity. Potential differences in water quality between alternative source waters should be considered when determining the applicability of the CT values needed for ONWS systems.
- The Australian WaterVal Validation Protocol for chlorine disinfection provides CT values for 1- to 4-log reduction values of viruses for a range of turbidity, pH, and temperatures (WaterSecure 2017b). California state regulators are using these CT values for the

crediting of free chlorine disinfection in recycled water and could be considered for use in ONWS settings as well.
- To obtain free chlorine disinfection credit, there must be a measurable free chlorine residual exiting the reactor.

A significant obstacle for the implementation of a free chlorine disinfection strategy is the presence of ammonia in the feed water – blackwater and graywater systems could have significant levels of ammonia in their raw source waters. Ammonia reacts with free chlorine to form the less potent chloramine species – shown in Figure 16.

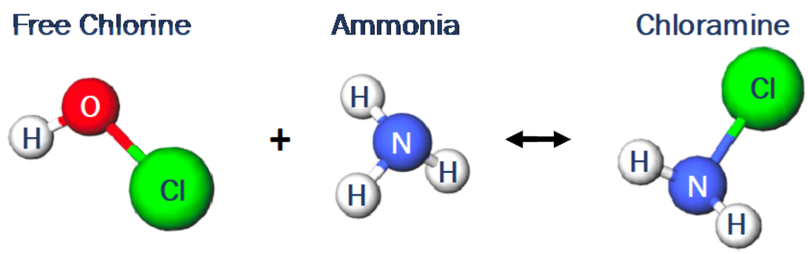


Figure 16. The Reaction of Free Chlorine and Ammonia to Form Chloramine.

One strategy for dealing with ammonia is breakpoint chlorination, where sufficient free chlorine is added to oxidize all the ammonia. Once the free chlorine completes the ammonia breakpoint reaction, any additional chlorine added will remain in its free chlorine form. The downside of the breakpoint approach is that it requires high doses of chlorine to oxidize any ammonia present (often 8-10 mg/L of chlorine to breakpoint 1 mg/L of ammonia). Control systems will be needed for systems seeking free chlorine credit to ensure that the potential presence of ammonia does not lead to the conversion of free chlorine to chloramine. One option is to install free chlorine-specific meters for the verification of the appropriate residual concentration.

Another strategy for dealing with ammonia is reliable upstream control of ammonia through nitrification. If operated appropriately, biological treatment can consistently reduce ammonia levels to below 0.5 mg/L. Regardless of how the ONWS system controls ammonia, it should be considered a priority if disinfection with chlorine will be pursued. Generally, systems with significant ammonia levels cannot be relied upon for disinfection of viruses or protozoa.

The appropriate CT value to use for design should be evaluated on a case-by-case basis. Some examples of potential situations are presented in Table 13.

Table 13. Examples of CT Requirements for Various Free Chlorine Disinfection Applications.

Source Water Type	Treatment Train	Water Quality at Point of Chlorination Most Similar to:	Pay Attention to:	Likely Applicable CT:
Rainwater	Cartridge Filtration + Free Cl_2	Surface water	Turbidity, Organics	EPA CT Tables
Graywater	Engineered Wetland + UV + Free Cl_2	Oxidized, filtered wastewater	Turbidity, Organics, Ammonia	Australian WaterVal
Blackwater	MBR + UV + Cl_2	Oxidized, filtered wastewater	Turbidity, Organics, Ammonia	Australian WaterVal

In the absence of CT tables, granting bacterial inactivation by chlorine should be done on a treatment train-specific basis. Past studies have shown that turbidity has a significant impact on the chlorine inactivation of bacteria in recycled waters. Consequently, the CT framework should only be used for bacterial crediting with free chlorine if the disinfection process has been preceded by membrane filtration, MBR, or RO (i.e., filtration processes that produce low-turbidity effluents). Through consultation with the ONWS Expert Panel, it is recommended to grant bacteria inactivation credit for free chlorine disinfection that is equivalent to the virus credit received if it is preceded by either a membrane filter, MBR, or RO that meets the turbidity requirements for filter crediting. For example, a train providing free chlorine disinfection downstream of an MBR could dose in sufficient chlorine to achieve a free chlorine residual (C) of 2 mg/L after a contact time (T) of four minutes leading to a CT of 8 mg-min/L. Using the CT tables from the Australian WaterVal report, a CT of 8 mg-min/L provides 4-log virus inactivation at 20˚C for a membrane filtered water (i.e., turbidity $\leq$0.2 NTU). In this scenario, bacteria inactivation credit would also be equivalent to 4 logs. Additional work is needed to develop a bacteria CT crediting approach for free chlorine for treatment trains without membrane filtration.

Chlorine Contact Time

At the municipal scale, chlorine contact time is typically characterized using a tracer study to develop a profile of the flow through a contact basin or pipeline. Conducting a tracer study can be prohibitively expensive or impractical for ONWS systems; therefore, Design Engineers may opt to use 'rule of thumb' baffling factors to determine contact time in the absence of tracer data. The baffling factor is multiplied by the average hydraulic retention time to obtain the contact time for the CT calculation (see Equation 1). A lower baffling factor will result in a lower CT credit and thus less pathogen credit, and vice versa.

$$Contact\ time = Baffling\ factor * Average\ HRT \qquad \text{(Equation 1)}$$

The classifications of reactors by baffling factors provided by the EPA is presented in Table 14. A common configuration for ONWS systems is to use a large cylindrical tank for chlorine disinfection. Based on the description provided in Table 14 for an unbaffled basin, it is recommended that a cylindrical chlorine contact tank should assume a baffling factor of 0.1. An alternative configuration, such as a pipeline contactor, could be used to achieve a higher baffling factor; the appropriate baffling factor to assume in the absence of tracer data would need to be evaluated on a case by case basis, but would likely be at least 0.5.

Some states have developed guidance in addition to what has been provided by the EPA. For example, Colorado has a Baffling Factor Guidance Manual, the goal of which is to help small-scale water systems (tanks less than 5,000 gallons and flow rates up to 50 gpm) determine baffling factors for different reactor configurations. This document provides specific criteria that can be used to assign baffling factors (Table 15); for example, a pipeline contactor with a total length (L) to diameter (D) ratio (L/D) of greater than or equal to 160 can use a baffling factor of 1 (provided it meets a minimum specified flowrate). It also contains guidance for non-pressurized tank systems, commonly used in ONWS systems, to increase their baffling factor by making design modifications such as the inclusion of an inlet manifold and the use of packing material.

Table 14. Baffling Classifications for Reactor Configurations.

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

Table 15. Example of Guidance Provided in
Colorado Department of Public Health and Environment Baffling Factor Guidance Manual.
The baffling factors in this table apply for pipeline contactors with pipe diameters between 4 and 12 inches.
L = length; D = diameter.

Baffling Factor	Requirements
1	L/D ratio ≥ 160 Meets minimum main run length and flow rate requirements.
0.7	40 ≤ L/D < 160 Turbulent flow, i.e., Reynolds Number > 4000
0.6	L/D ratio ≥ 160 Meets minimum main run length but *does not* meet minimum flow rate requirements.

Chlorine Contact Design Guidance

In order to receive disinfection credit, chlorine contactors must meet the following three criteria:

- All water entering the chlorine contactor must be chlorinated prior to entering the contactor.
- Chlorine cannot be added in an internal recirculation loop (see the examples of inappropriate chlorine contact configurations in Figure 17).
- The chlorine residual measurement used as the C in CT must be measured in the contactor effluent.

Some potential configurations involving tank chlorine contactors are shown in Figure 17.

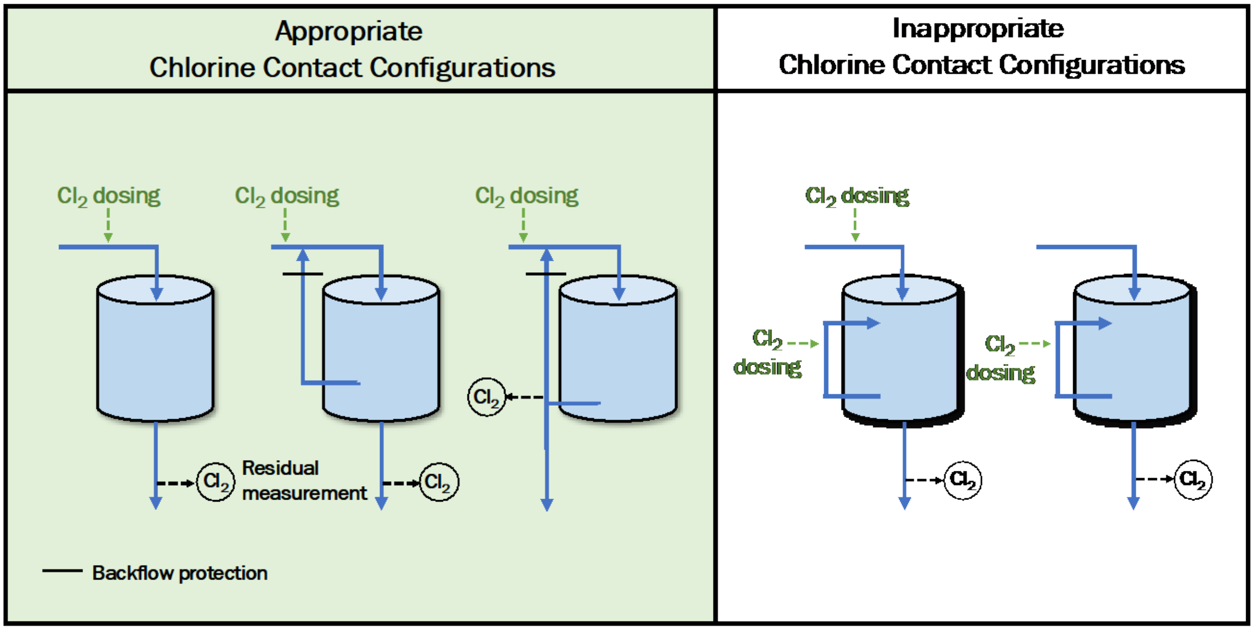


Figure 17: Example Chlorine Contact Configurations Using a Tank.
Appropriate configurations are marked in green; configurations in red should not receive CT credit.
Similar configurations also apply to ozone disinfection.

UV Disinfection

Unlike chlorine, UV disinfection can provide significant protection against *all* classes of pathogens from virus, to protozoa, to bacteria. UV systems also benefit from a smaller footprint, no chemical requirements, and potentially easier operation because treatment is more resistant to water quality changes, such as ammonia bleedthrough. As a result, UV will likely be a common form of disinfection in many ONWS treatment trains. One of the drawbacks of UV, however, is that proper design and operation requires an understanding of the complexities of UV reactor validation and pathogen crediting. While EPA has provided significant guidance for the design and operation of large-scale, municipal UV systems, there is less guidance for smaller-scale UV reactors that are more applicable to ONWS settings (EPA, 2006). This section intends to simplify the UV discussion by focusing on two frameworks that are relevant to ONWS: 1) the EPA's UV Disinfection Guidance Manual (UVDGM) and 2) the NSF International's NSF 55A standard for Ultraviolet Microbiological Water Treatment Systems (EPA, 2006; NSF, 2019). For further information on these and other validation frameworks, Regulators, Design Engineers, and other interested stakeholders should reference the Additional Resources listed at the end of the chapter or seek consultation from professionals with experience in UV design and permitting.

UV Background

Ultraviolet light (UV) irradiation is a commonly used disinfection process for drinking water, wastewater, and water reuse applications that involves generating and transmitting UV light to inactivate pathogens. The principle mechanism of disinfection is damage to the nucleic acids that are essential for replication. Crediting for UV disinfection is based on a UV dose, which is analogous to the "CT" framework for chemical disinfectants. UV dose is calculated as the product of the amount of UV light emitted by the system and the duration of exposure to the light source, as described in Equation 2. EPA and other similar bodies have developed UV inactivation tables, similar to chlorine CT tables, that relate UV dose to the inactivation of viruses and protozoa.

$$UV\ dose\ \left(\frac{mJ}{cm^2}\right) = \ UV\ intensity\ \left(\frac{mW}{cm^2}\right) * Residence\ time\ (s) \qquad \text{(Equation 2)}$$

The process for determining and verifying UV dose, however, varies significantly from that used in chemical disinfection systems. The two main strategies for monitoring the dose provided by a UV reactor are:

- UV Intensity Setpoint Approach.
- Calculated Dose Approach.

The dose-monitoring strategy is an important design consideration because it impacts how the reactor is validated, what parameters are used to confirm the UV dose, and how the reactor is operated. The simpler of the two approaches is the UV Intensity Setpoint approach. This approach relies on maintaining the UV intensity – a parameter that can be measured continuously by a UV intensity meter – at or above a minimum setpoint that has been established through validation testing. As long as the UV intensity reading meets or exceeds the minimum values established during testing, the reactor is providing the validated dose.

As an example, a set of theoretical test conditions and results for a reactor validated for 40 mJ/cm² is presented in Figure 18. The conditions frequently span a range of flow rates and UVTs, since higher flow rates and lower UVTs lead to lower UV doses. Throughout testing, the flow, UVT, and UV intensity are measured at the same time that the UV dose is determined (Table 16 describes the importance of each parameter). The "operating envelope" is the set of conditions in which the UV reactor could meet or exceed the specified UV dose. In this example, the reactor achieved the 40 mJ/cm² dose at the two flow rates tested (i.e., both low and high), but only down to a UVT of 75% at the higher flow rate. The operating envelope therefore requires that the system be operated within the flow rate range tested and above the minimum UVT.

Validation Testing Conditions	UV Intensity (mW/cm²)	UV Dose (mJ/cm²)
Low flow, high UVT	15	80
High flow, high UVT	12	60
Low flow, low UVT (75%)	12	60
High flow, low UVT (75%)	10	40
High flow, lowest UVT (65%)	8	35

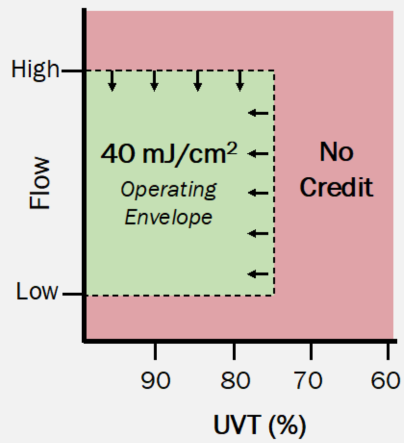


Figure 18. Sample Test Conditions and Data from a UV Reactor Validated for a 40 mJ/cm² Dose with the Intensity Setpoint Approach.

One benefit of the UV intensity setpoint method is its simplicity. The only parameters that need to be measured to ensure performance are flow rate and UV intensity. Notably, the UV intensity setpoint does not require monitoring of UVT since the UV intensity reading will also reflect changes in UVT (i.e., lower UV intensity with lower UVT)[4]. In the example above, the UV intensity must be at least 10 mW/cm² to ensure the system is within its operating envelope. The other benefit of this approach is that it is conservative. Reactors validated by this method receive credit for the same UV dose in the full range of their operating envelopes. In other words, because the validated dose is provided under the most challenging conditions, the reactor provides *greater* performance under less challenging conditions. Consequently, EPA recommends the use of the UV Intensity Setpoint approach for small water systems in their UV Disinfection Guidance Manual (EPA, 2006). **Given its benefits in terms of operational simplicity and performance reliability, the UV Intensity Setpoint approach is the recommended approach for ONWS in this Guidance Manual.**

[4] While the UV Intensity Setpoint approach does not require continuous measurement of UVT, the Design Engineer should reference the data from the validation testing when selecting a UV reactor. For example, if an ONWS application is anticipated to have a UV feedwater UVT of 65%, the Design Engineer should focus on selecting UV reactors that have been validated at or below 65% UVT; reactors validated at higher UVTs will not be able to provide the validated dose at those operating conditions.

Table 16. UV Validation Parameters and Their Importance.

Parameter	Notes
UV Intensity	UV Intensity is the measurement of the UV output of a lamp, which can be measured continuously by a sensor inside a UV reactor. Several factors can impact the measured UVI: • Lamp aging: UV output from lamps diminishes over time, resulting in reduced UV intensity. • Fouling of quartz sleeves: Fouling is caused by deposition of inorganic and organic constituents on the outside of UV lamps. Fouled sleeves will allow less light from UV lamps to reach the water in the reactor, thus reducing UV intensity. • Water quality: the UV transmittance of water has a direct impact on the ability of UV radiation to penetrate the water surrounding a lamp.
UV Transmittance	The UVT quantifies the percent of UV light at 254 nm not absorbed while passing through the water column; higher UVT values mean more UV light can pass through, improving disinfection efficacy. Dissolved materials, turbidity, and suspended solids can all absorb UV light and reduce a water's UVT. Lower UVTs will result in a decrease in measured UV intensity and thus a lower UV dose.
Flow Rate	The hydraulics of UV reactors are a key component of their ability to provide a given dose level. The flow rate through a reactor is directly related to the residence time provided in that reactor. Flows that are higher than a validated limit will result in water travelling too fast through the reactor to guarantee that the desired dose is being achieved. Conversely, low flows can also result in short-circuiting effects that can cause pockets of water to see very little UV light.

Two relevant UV validation frameworks that use the UV Intensity Setpoint approach are the EPA UVDGM and the NSF 55A standard. These two frameworks are the focus of this Guidance Manual since many reactors used in ONWS settings are validated under them[5]. One reason for the prevalence of these frameworks is that they do not require costly, site-specific challenge testing. This stems from the fact that systems using the UV Intensity Setpoint are designed and operated using the conservative assumptions described above. NSF55A requires validation to achieve a single UV dose of 40 mJ/cm^2 while UVDGM provides greater flexibility to validate for a range of UV doses. Nevertheless, many small-scale UV reactors validated under UVDGM are also validated for 40 mJ/cm^2. The next section describes how to assign pathogen log reduction credit to UV reactors that have been validated under these two frameworks.

[5] Reactors validated under other validation frameworks that use the UV intensity setpoint should also be considered, including the German Gas and Water Association DVGW 294 standard and the Austrian ÖNORM standard.

UV Pathogen Crediting

UV validation includes assessing the ability of a reactor to inactivate microorganisms. In most frameworks, validation testing does not take place with actual pathogens (like *Giardia* or enterovirus), but with a "challenge microorganism" that is non-pathogenic to humans such as viruses that infect bacteria (e.g., coliphages) or bacteria. One common challenge microorganism is MS2 coliphage. One of the challenges with the crediting of *pathogen* reduction through UV is translating the validation data – which reports inactivation of a challenge microorganism – into log reduction credits for actual pathogens. This translation is specific both to a) the type of challenge microorganism used and b) the pathogen of interest. To simplify the discussion, this research assumes that MS2 is used as the challenge microorganism based on the fact that a) NSF55A *requires* the use of MS2 for validation testing, and b) UVDGM allows for the use of MS2 and is frequently undertaken with this organism.

While NSF55A requires validation to verify a dose of 40 mJ/cm^2, a range of validated UV reactors are available. Table 17 summarizes some common validated UV doses and the level of pathogen log reduction credit that could be assigned for each system. As stated, determining pathogen credits depends on the challenge organism (in this case, MS2) and the target pathogen or surrogate of interest. For viruses, the LRTs that were developed are based on the reduction of enteric viruses (Sharvelle et al., 2017). It is therefore appropriate to establish virus crediting based on MS2 inactivation since this bacteriophage has often served as a surrogate for enteric virus reduction – e.g., polio virus – in other regulatory contexts (State Water Resources Control Board, 2018; NWRI, 2012). The recommended approach for virus crediting is therefore to base credits on the standard MS2 dose-response curve from NWRI (2012). The crediting for protozoa is based on the conversion from MS2 to *Cryptosporidium* and *Giardia* using the bias factors described in the UVDGM (EPA, 2006). EPA does not provide recommendations for calculating bacterial inactivation credits through UV systems. As a workaround for this Guidance Manual, bacteria log reductions were set equivalent to the virus log reductions under the assumption that virus will provide a conservative estimate of inactivation. Regulators in each jurisdiction may choose to credit bacteria differently since there is not specific guidance from EPA or another regulatory body on this topic. Readers are referred to Section 3.1 for additional discussion on the challenges of bacterial log reduction crediting.

Table 17. Summary of Pathogen Credits for UV Systems Validated with MS2 Challenge Testing.
Virus credit based on standard MS2 dose-response curve (NWRI 2012). Bacteria credit conservatively based on virus credit. Protozoa credit based on recommendations from EPA (2006).

Validated Dose[1]	Virus Credit	Protozoa Credit	Bacteria Credit
40	2	3	2
80	3.5	6	3.5
100	4.25	6	4.25
150	6	6	6

1. This dose table is intended to apply for validation protocols using MS2.

It is important to note that it is insufficient to select a validated reactor alone – the Design Engineer should also provide the Regulator with documentation describing the validated operating envelope and how the UV system will be designed and operated to stay within the acceptable limits for flow, UVT, and other relevant parameters. Another note of caution is that NSF55A has historically focused on validating very small units for potable drinking water applications. Consequently, the validated operating envelops are often at the high UVTs relevant for drinking water (e.g., >95% UVT). It is not anticipated that ONWS source waters will have UVTs of 95% (except possibly for rainwater). Some NSF55A reactors, however, will have validation data at lower UVTs and these reactors are anticipated to be the most relevant for most ONWS applications.

UV Disinfection: Lessons Learned

One option to streamline the UV design and permitting process is to create a list of pre-approved, validated UV reactors that can be shared with Design Engineers and System Owners during the design phase. By creating a pre-established list, the Regulators are assured that the UV reactors meet the criteria for ONWS, while streamlining the selection process for Design Engineers. In developing this list, Regulators should undertake a careful review of the UV validation reports to determine the appropriate operating envelopes, particularly with regard to UVT. It is recommended that Regulators and Program Administrators create similar lists for UV and other relevant equipment.

Ozone Disinfection

Ozone is commonly used in drinking water both for disinfection and to control taste and odor issues. It is also used in recycled water contexts for color removal. In addition to being effective at inactivating viruses, *Giardia*, and *Cryptosporidium*, it can also oxidize and break down organic matter. Ozone disinfection systems generally have four main components: a gas feed system, an ozone generator, an ozone contactor, and an off-gas destruction system. The gas feed system provides a source of oxygen to the generator, which generates ozone that is then delivered into the contactor. While most (>80%) of the ozone gas will be dissolved into the water, some will be released from the contactor as off-gas. This ozone off-gas should be captured and destroyed so that it doesn't escape into the surrounding room or environment because the concentrations present can be toxic.

Ozone Pathogen Crediting

Ozone disinfection credit is based on the CT framework and therefore requires measurement of both the ozone residual concentration and the contact time. A key difference is that whereas chlorine is typically injected in liquid form, ozone is injected as a gas, and thus some amount of time is needed to dissolve it into the liquid. In addition, ozone reacts quickly in water and thus the residual can drop very rapidly along the length of a contactor. The defined period of contact time used for calculating the ozone CT should not include the time needed to effectively mix the ozone into the water, nor the time required for ozone to dissolve. More specific information regarding how to calculate ozone CT for virus, *Giardia*, and *Cryptosporidium* can be found in the EPA documents identified at the end of this chapter.

As with chlorine, there are currently no CT tables linking ozone dose to bacterial inactivation. Therefore, it is not recommended to grant bacteria inactivation credit based on the CT framework. Until a validated CT framework is developed, effluent coliform monitoring could be used to demonstrate ozone performance. Additional research in this area is recommended to develop a bacterial reduction framework for ozone.

Ozone Safety

Safety is an important consideration for ozone, particularly in ONWS systems. At the municipal scale, ozone is often isolated from the rest of the treatment system, either in its own room or in a separate building. This is likely not feasible in many building-scale applications because of space constraints. Ozone processes can generate significant heat and potential ozone gas leaks, requiring more stringent considerations for ventilation and exhausting of air from the site. Because ozone is very dangerous above fairly low concentrations, ambient ozone monitoring should be provided. An alarm should be set for an ambient ozone concentration of 0.1 mg/L; further guidance should be sought in local building and fire codes.

Summary of Disinfection

Table 18 provides information comparing the three types of disinfection technologies described in this chapter.

Table 18. Summary of Considerations for Disinfection Technologies.

Treatment Process	Pathogen Credit	Pros	Cons
Chlorine Disinfection	4-log Virus 4-log Bacteria[1]	• Effective virus control, if free chlorine residual is obtained. • Common disinfectant. • Capable of serving as both disinfectant and distribution system control.	• Limited control of *Giardia* and ineffective for *Crypto.* • Requires footprint for infrastructure providing contact time. • Requires chemical handling considerations.
UV Disinfection	6-log Virus 6-log Protozoa 6-log Bacteria	• Robust protection against all pathogen types. • Highly effective against protozoa. • Small footprint. • Lower chemical costs.	• Requires additional chlorine for distribution system control. • Higher energy costs.
Ozone Disinfection	4-log Virus 3-log Protozoa	• Effective for disinfection of viruses, protozoa, and bacteria. • Effective control of color and odor.	• High capital cost. • High energy cost (will depend to some degree on ozone dose used). • Requires additional safety measures. • Requires additional chlorine for distribution system control.

1. The CT framework should only be used for bacterial crediting with free chlorine if the disinfection process has been preceded by membrane filtration, MBR, or RO (i.e., filtration processes that produce low-turbidity effluents).

3.7 Distribution System Management

DESIGN ENGINEER

The **Design Engineer** should consider the water quality goals presented in Table 19 to maintain the aesthetic acceptability and microbial stability of the distribution system.

After treatment to comply with all the LRTs and other water quality requirements, the Design Engineer should consider the water quality of the ONWS effluents in the distribution system. The distribution system consists of all the plumbing that links the final treatment process to the point of use (i.e., toilet, sprinkler, washer, etc.). The degradation of water quality in the ONWS distribution system may adversely impact the aesthetics at the point of use (color, odor), maintenance requirements (microbial regrowth, scaling, corrosion), and public health (opportunistic pathogens such as *Legionella*). Establishing goals and designing to maintain a high-quality effluent in the distribution system is recommended. The Design Engineer and Regulator should consider the type of building and the use patterns of its occupants – particularly commercial buildings that may have little to no water usage over weekends and holidays – to ensure adequate distribution system water quality at all times. Sample water quality goals are presented in Table 19.

Table 19. Distribution System Water Quality Goals.

Parameter	Average	Maximum
BOD	< 10 mg/L (4-week)	25 mg/L
TSS	< 10 mg/L (4-week)	30 mg/L
Odor	The system shall not emit offensive odors	
Chlorine residual at or near point of use	0.2 mg/L free chlorine residual, *or* 0.5 mg/L combined chlorine residual	

Additionally, the following best management and design practices are recommended to further minimize adverse impacts in the distribution system:

- For blackwater and graywater, implement reliable and high-quality biological treatment with nitrification to provide a high degree of organics destruction and nutrient removal, helping to minimize microbial regrowth.
- Select non-reactive piping materials for the construction of the distribution system, e.g., avoid iron pipes that react with chlorine to reduce residual concentrations in the distribution system.
- Consider pipe sizing and flow velocities.
- Avoid dead spots or stagnation in the piping runs.
- Design the distribution system for periodic flushing and cleaning capabilities.
- Install sample ports at terminal locations in the distribution to allow for periodic measurement of chlorine residual.
- Control for temperature (i.e., reduce temperature of treated water) to the extent possible.

3.8 Summary of Treatment Selection and Crediting

The goal of Chapter 3 is to provide the Design Engineer with enough information to begin making informed decisions considering what treatment processes to select for an ONWS system, and how that system will comply with the LRTs to protect public health. The concept of pathogen crediting was introduced, giving the Design Engineer an understanding of the log reduction provided by each type of treatment process. If a treatment process does not have an existing crediting framework, the water quality and/or operational benefits of the system were described, and the concept of site-specific validation was introduced.

This chapter focused on five key treatment process groups: flow equalization, pretreatment, biological treatment, filtration, and disinfection. Primary treatment goals were introduced and discussed, and the most common treatment technologies currently used for ONWS systems were described in detail, including any available pathogen crediting frameworks that could be applied to the treatment process.

The Design Engineer should consider the following drivers and constraints when evaluating and selecting and appropriate ONWS treatment processes:

- Feed water quality to the treatment system.
- Downstream or end use water quality objectives.
- Residual waste stream treatment and/or disposal.*
- Site constraints including footprint and access.
- Energy usage.
- Economics (both capital and operating costs).
- Ease (or complexity) of operation and maintenance.
- Resiliency to handle source water variability.
- Reliability to ensure uptime and production.

*A majority of ONWS systems in urban areas will be located in structures that are connected to or are near a sewer line. In this case, the residual waste streams such as screenings, sludge, and brine may be able to be discharged directly to the sewer for treatment at the municipal wastewater treatment plant. Check with the wastewater utility to see if this disposal option is allowable. If a sewer connection is not available or accessible, then sludge waste handling and disposal can become a significant design consideration.

3.9 Additional Resources

Pathogen Crediting

Branch, A. and Le-Clech, P. (2015) National Validation Guidelines for Water Recycling: Membrane Bioreactors. Brisbane, Australia.

EPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.

EPA (1999) Disinfection Profiling and Benchmarking Guidance Manual.

EPA (2005) Membrane Filtration Guidance Manual.

EPA (2006) Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule.

EPA (2010) Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual.

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H. and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

Biological Treatment

Branch, A. and Le-Clech, P. (2015) National Validation Guidelines for Water Recycling: Membrane Bioreactors. Brisbane, Australia.

EPA (2012) Guidelines for Water Reuse. EPA/600/R-12/618. Washington, D.C.

Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse. McGraw-Hill, Boston.

WaterSecure (2017a) Membrane bio-reactor: WaterVal validation protocol. Australian WaterSecure Innovations. Brisbane, Australia.

WEF, ASCE, and EWRI (2010) Design of Municipal Wastewater Treatment Plants, Volume 1: Planning and Configuration of Wastewater Treatment Plant, Fifth Edition, McGraw-Hill, New York.

WEF, ASCE, and EWRI (2010) Design of Municipal Wastewater Treatment Plants, Volume 2: Liquid Treatment Processes, Fifth Edition, McGraw-Hill, New York.

Filtration Design

EPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.

EPA (2005) Membrane Filtration Guidance Manual.

EPA (2012) Guidelines for Water Reuse.

Disinfection Design

Colorado Department of Public Health and Environment (CDPHE). (2014) Baffling Factor Guidance Manual: Determining Disinfection Capability and Baffling Factors for Various Types of Tanks at Small Public Water Systems. CDPHE Water Quality Control Division, Safe Drinking Water Program.

EPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.

EPA (1999) Disinfection Profiling and Benchmarking Guidance Manual.

NSF (2019) http://www.nsf.org/regulatory/regulator-nsf-standards. Complementary copies of the NSF 55 standard are available to regulators by completing the regulatory inquiry form at the website.

NWRI (2012) Ultraviolet Disinfection: Guidelines for Drinking Water and Water Reuse, 3rd Edition.

San Francisco Public Utilities Commission, Validated UV Systems List. (https://sfwater.org/Modules/ShowDocument.aspx?documentID=11821).

State Water Resources Control Board (2018). Regulations Related to Recycled Water. Updated October 1, 2018.

WaterSecure (2017b) Chlorine Disinfection: WaterVal validation protocol. Australian WaterSecure Innovations. Brisbane, Australia.

Distribution System and Water Quality

ANSI/ASHRAE Standard 188-2015.Legionellosis: Risk Management for Building Water Systems. Atlanta, GA. American National Standards Institute (ANSI)/ASHRAE Standard 188-2015, 2015.

Jjemba, P., Weinrich, L., Cheng, W., Giraldo, E., and M.W. LeChevallier. (2010) Guidance Document on the Microbiological Quality and Biostability of Reclaimed Water Following Storage and Distribution (WRRF 05-02). WateReuse Research Foundation, Alexandria, VA.

Thomure, T.M., Rock, C., Choi, C., Williams, D.S., Pepper, I., McLain, J., Lansey, K., and R. Rahman. (2014) Approaches to Maintaining Consistently High-Quality Recycled Water in Storage and Distribution Systems. WateReuse Research Foundation, Alexandria, VA.

Weinrich, L.A., Jjemba, P.K., Giraldo, E., and M.W. LeChevallier. (2010) Implications of organic carbon in the deterioration of water quality in reclaimed water distribution systems. *Water Research*, 44, 5367-5375.

4 Developing Multiple-Barrier ONWS Systems

This chapter addresses the key learning objectives for the Design Engineer, Regulator, and Operator with regard to the development of ONWS systems that employ multiple barriers to protect public health. The specific learning objectives for this chapter are shown in Figure 19.

Chapter 4 Key Learning Objectives	
DESIGN ENGINEER	• Use of treatment and management barriers in development of multiple-barrier ONWS systems • Appropriate treatment & monitoring for different source and end use combinations
REGULATOR	• Benefits of treatment and management barriers for public health protection • Evaluation of treatment & monitoring strategies for different source and end use combinations
OPERATOR	• Key treatment and monitoring concepts • Role of operations in ensuring LRTs are continuously met

Figure 19. Chapter 4 Key Learning Objectives.

The multiple-barrier approach has been a cornerstone in the design of water treatment systems, from surface water treatment to potable reuse. This chapter takes a wide view of the various barriers that can be used – both treatment and non-treatment barriers – and describes how they can be used in combination to meet ONWS objectives. The main goal of any treatment system is to ensure **reliability** in terms of public health protection: the system must make safe water. At the same time, the system should seek to achieve high degrees of **availability,** or system uptime, in order to maximize the investment and use of the new non-potable supply. While treatment most often comes to mind when thinking of the multiple-barrier approach, it is important to note that there are both treatment barriers and non-treatment (i.e., management) barriers that can be employed. This chapter discusses the benefits of these barriers and how they can be combined to design safe ONWS systems.

4.1 Benefits of Multiple Barrier Trains

During the treatment of water, there may be a wide diversity of contaminants to remove (e.g., pathogens, biodegradable organics) and water quality goals to achieve (e.g., reduction of suspended solids, turbidity, color, and odor). Frequently, there is no single barrier that can meet all of the treatment and water quality criteria alone. In the context of ONWS, the main contaminant group of concern is the pathogens, with LRTs assigned for virus, protozoa, and bacteria. While not specified by the Expert Panel, additional water quality requirements may be imposed on ONWS systems including reductions in biodegradable organics (e.g., BOD) and suspended particles (e.g., TSS and turbidity). Table 20 provides a qualitative estimate of the ability of different unit processes to control this large range of water quality objectives. What emerges immediately is that no single unit process can effectively address all of these issues. The use of multiple treatment barriers is therefore likely to be necessary for many alternative building source waters, particularly those with higher degrees of contamination, such as graywater and blackwater. The following sections discuss the benefits of designing treatment systems with multiple barriers including both treatment and non-treatment barriers.

Table 20. Benefits of Treatment Barriers.

Unit Process	Pathogens			Water Quality		Removal / Inactivation Mechanisms
	Virus	Protozoa	Bacteria	Particulates	Organics	
Biological Treatment						
Non-membrane options	Red	Yellow	Yellow	Yellow	Green	Biodegradation, adsorption, predation
MBR	Yellow	Green	Green	Green	Green	Same as above plus size exclusion
Filtration						
Granular media filter	Red	Yellow	Yellow	Green	Red	Physical removal (e.g., size exclusion, interception, diffusion)
Cartridge filter	Red	Yellow	Red	Green	Red	
Membrane filter	Red	Green	Green	Green	Red	Physical removal (e.g., size exclusion)
Reverse osmosis	Green	Green	Green	Green	Green	
Disinfection						
UV	Green	Green	Green	Red	Red	Physical degradation
Free chlorine	Green	Red	Green	Red	Red	Chemical inactivation and oxidation
Chloramine	Red	Red	Green	Red	Red	
Ozone	Green	Yellow	Yellow	Red	Red	

Legend:
Green: Process is effective at reducing indicated contaminant.
Yellow: Process is somewhat effective at reducing indicated contaminant.
Red: Process is not effective at reducing indicated contaminant.

Robustness

The first benefit of multiple barrier treatment trains is that they provide a greater diversity of "mechanisms" to remove contaminants. In EPA's Surface Water Treatment Rule, for example, there is a requirement to provide two mechanisms of control – filtration and disinfection – when treating surface waters. Granular media filtration is a physical removal process that is effective at removing suspended particles from the water. Consequently, it provides an important barrier against larger pathogen classes, such as *Giardia* and other protozoa. It is less effective, however, at removing smaller pathogens such as viruses. That being said, a common disinfection process like chlorine is highly effective against viruses while being only moderately effective against *Giardia*. The combination of these processes provides a diversity of mechanisms to remove or inactivate pathogens. This *treatment* diversity improves the system's ability to control *pathogen* diversity.

As discussed in Chapter 3, many ONWS systems will likely require a combination of both filtration and disinfection processes to meet the LRT requirements. Within the categories of filtration and disinfection there is even further diversity that can be leveraged. For example, disinfection can utilize various mechanisms including chemical inactivation (e.g., free chlorine, chloramine, and ozone) as well as physical inactivation (e.g., UV irradiation or heat). Combining different filtration and disinfection processes provides opportunities to ensure all pathogen classes are adequately addressed.

For blackwater and many graywaters, biological treatment will also be needed to meet water quality objectives related to BOD, TSS, and aesthetics. The combination of these three types of processes – biological treatment, filtration, and disinfection – provides even greater numbers of reduction mechanisms. In so doing, multiple barriers enhance the system's **robustness**, i.e., *the ability of a treatment system to address a broad variety of contaminants*. An overview of the types of removal or inactivation mechanisms is provided in Figure 20.

Robustness also promotes public health reliability by decreasing the chances of a complete or catastrophic failure. If a single unit process has a certain probability of failing (P=0.1), then the probability that two barriers fail at the same time is P×P (0.01). Additional barriers will further reduce this probability of a catastrophic failure. As stated above, however, the degree of treatment (and the number of processes) should be commensurate with the treatment requirements. In other words, a source water with higher degrees of contamination (e.g., blackwater) will require higher treatment and more barriers than a less-contaminated source water (e.g., rainwater).

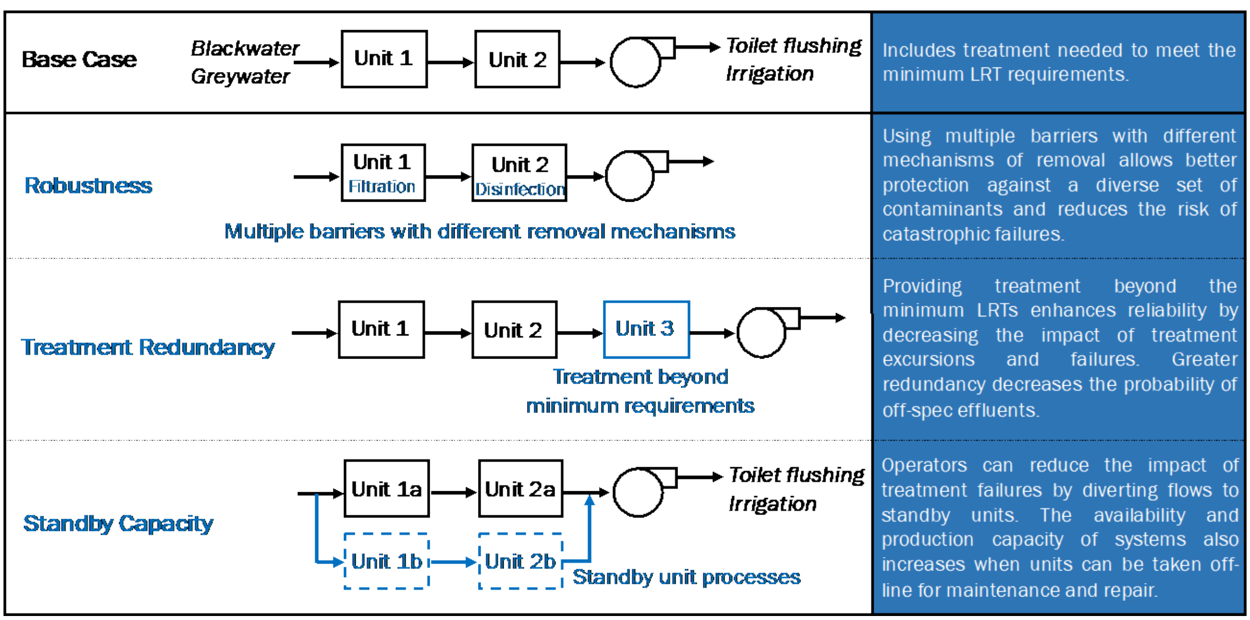


Figure 20. Different Applications of Treatment Barriers to Improve the Reliability and Availability of ONWS Systems.

Redundancy

There are multiple forms of redundancy that are utilized in the design of water treatment systems. In this Guidance Manual, **redundancy** refers to *the use of treatment beyond the minimum requirements to ensure that treatment goals are more reliably met* (Figure 20). Redundancy promotes the overall goal of reliability by reducing the probability that a treatment excursion leads to a failure of public health protection. A system designed to provide 6-log reduction in viruses would provide 2 logs of treatment redundancy if the minimum LRT requirement was 4 logs. Such a system could withstand treatment excursions or failures that decreased performance by up to 2 logs while still meeting public health requirements. Many drinking water treatment plants utilize this strategy – e.g., providing an excess of disinfection to lower the risk that treatment or operational variability will result in off-spec water. Redundancy's first main benefit is to enhance system *reliability*.

Tolerance for Off-Spec Water

REGULATOR

PROGRAM ADMINISTRATOR

The ONWS Expert Panel emphasized the need for continuous process monitoring to provide real-time data on treatment performance. One of the key benefits of this strategy is the ability to provide a rapid response for systems that are out-of-specification in meeting the pathogen LRTs. **Regulators** and **Program Administrators** should determine the amount of off-spec water that is acceptable for their ONWS programs. The Expert Panel recommended specifying that treatment be designed and operated to achieve the LRTs no less than 95% of the time (tolerance for off-spec water limited to 5% or less).

System availability and operability is also improved through treatment redundancy. This benefit stems from the fact that redundant systems have a wider operational range within which to work before requiring a diversion or shutdown. A system designed to meet the minimum LRTs without any buffer (i.e., no redundancy), will need to enact operational responses every time there is a treatment excursion since that excursion will cause the overall LRTs to drop below the minimum. Diversions and shutdowns will require more complicated operations (lower operability) and will decrease the overall production capacity of the system by reducing up-time (lower availability).

Standby Capacity

Redundancy may also refer to the provision of standby capacity in a treatment train. To differentiate these uses in the Guidance Manual, *standby capacity* will be used to refer to the provision of units – in addition to the active or "duty" train – that can be utilized in the event of treatment or operational issues with the duty train (Figure 20). These issues could range from routine maintenance to system failures. Having standby capacity allows an Operator to rapidly switch trains during an excursion or failure, an action that promotes public health reliability. This flexibility also improves up-time and availability in that a unit in need of maintenance or repair can be taken offline without impacting system production.

Recommendation: Communicating About Design Decisions

DESIGN ENGINEER

SYSTEM OWNER

The **Designer Engineer** and **System Owner** should engage in frequent communication throughout the design process to ensure that the ONWS system is developed in line with each stakeholder's assumptions about performance, cost, operability, and other key issues. For example, designing ONWS treatment trains with a "safety factor" beyond the minimum LRTs (i.e., redundancy) will frequently increase the capital and O&M costs of the system, but may reduce the amount of time that the system is offline due to LRT compliance issues. Additional costs for a treatment "safety factor" may be acceptable if the ONWS system receives fines for being offline or out of compliance. Other features that enhance a system's up-time – such as having stand-by treatment units – increase both cost and footprint. Stand-by capacity may not be as critical for systems that have access to a municipal water supply and sewer system, but may be essential for systems that must serve as the sole source of treatment and water supply.

System Owners should be involved in these design decisions since they are often the party that is ultimately responsible for ensuring the performance, operability, and maintenance of the ONWS system. Design Engineers are encouraged to discuss the impacts of design decisions with System Owners throughout the process.

4.2 Benefits of Non-Treatment Management Barriers

In addition to treatment barriers, there are a number of management (non-treatment) barriers that can also be used to promote the goals of public health reliability and system availability. An overview of these barriers is provided in Figure 21.

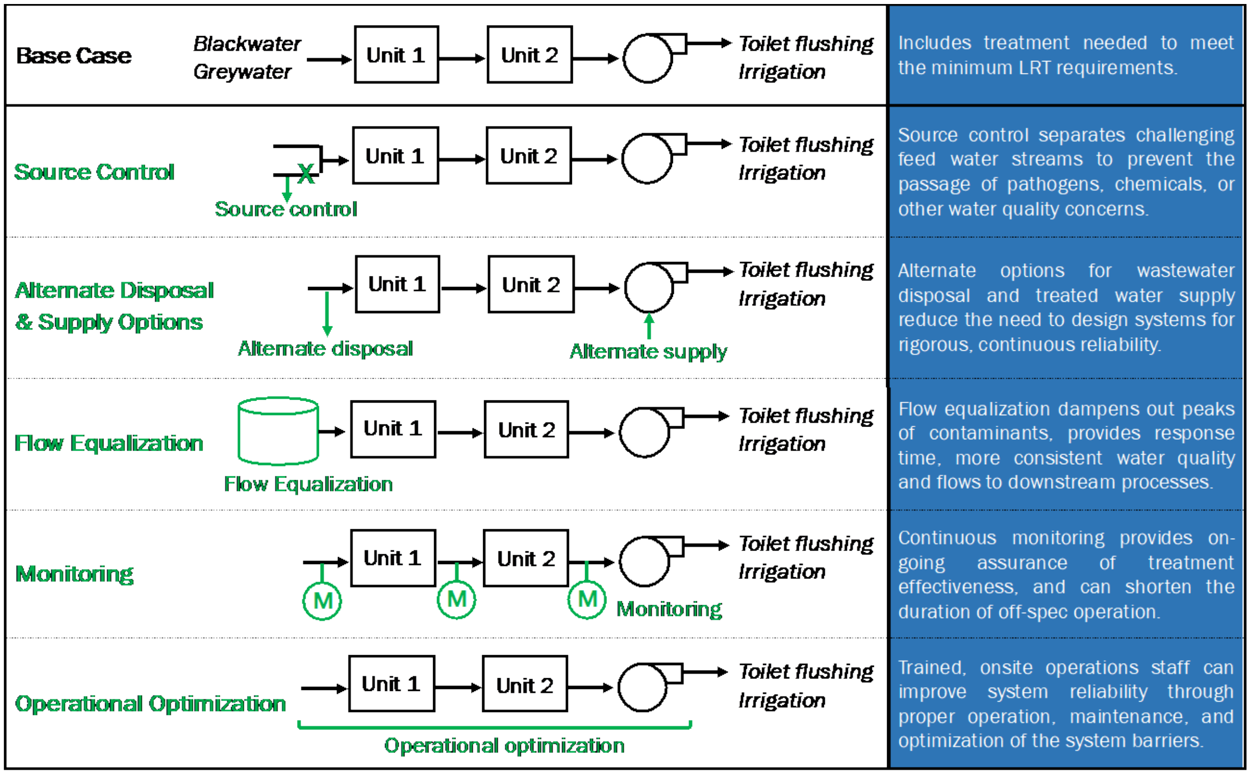


Figure 21. Examples of Non-Treatment (Management) Barriers
That Can Be Used to Improve ONWS System Reliability and Availability.

Source Control

One way to reduce the threat of contaminants in treated effluents is to prevent their introduction into the treatment system through source control (Figure 21). Industrial inputs are less likely to occur in an ONWS setting, meaning that black- and graywaters will often resemble municipal wastewaters in composition. Nevertheless, buildings that have commercial applications may consider some form of source control to limit the inputs from waste streams high in pathogens (e.g., hospitals or health laboratories) or chemicals (e.g., cleaners, technology companies). Technologies such as first flush diverters should be considered for rainwater and stormwater systems.

Alternate Disposal and Supply Options

The requirements for system design will vary greatly depending on whether the system has access to municipal sewer and water as back-up disposal and supply options (Figure 21). ONWS systems that serve as the sole option for wastewater discharge will need to be designed with rigorous requirements for system availability. Greater flexibility exists for systems that have the option to discharge wastewater to the municipal sewer. The same conditions hold for systems with regard to supply – buildings relying exclusively on the ONWS system for toilet flushing and irrigation supply will require stricter requirements than those having access to municipal potable supplies, or alternative supply options.

Flow Equalization

Systems that incorporate flow equalization provide multiple benefits for reliability (Figure 21). Flow equalization tanks provide a hydraulic buffer that can dampen out peaks of contaminants that may enter in the source wastewaters, protecting both downstream process function and treated effluent quality. The passage of water through the equalization tank also provides response time during which operations staff can address treatment or operational issues prior to the water being distributed. Finally, equalization enhances reliability by providing 1) a more stable quality of feedwater and 2) more even flows to downstream processes.

Monitoring

In putting together their guidance for ONWS, the Expert Panel specified two major requirements: 1) pathogen LRTs for different source waters and 2) the use of online monitoring to demonstrate that the pathogen barriers were consistently effective. **Monitoring is an essential element of ONWS systems**; it promotes reliability by rapidly detecting any upsets or excursions in treatment and alerting operations staff to enact responses to bring the process back into compliance (Figure 21). Multiple forms of performance monitoring are available, though many existing crediting frameworks rely on the use of surrogate monitoring because it can frequently provide a more continuous, high-frequency assessment of performance. See Chapter 3 for additional information on the monitoring requirements for different unit processes and crediting schemes.

Operational Optimization

The proper functioning of system barriers – both treatment and non-treatment barriers – relies on effective operations. Well-designed treatment systems can experience poor performance if operations staff are not well trained in the operation, maintenance, and optimization of the system. ONWS systems may experience different challenges than municipal systems in that they are less likely to have dedicated, full-time operations staff onsite, and may need to rely on higher degrees of automation overseen by remote, offsite staff.

4.3 Balancing Treatment and Non-Treatment Elements in a Multiple-Barrier System

Design Engineers have access to a number of elements that can be used to create ONWS systems that are safe and reliable, while also providing high up-time and operability. This range of options provides Design Engineers with the flexibility to utilize different combinations that best fit the constraints of a given site. For example, in large, densely constructed cities, the footprint available for an ONWS system may be a significant constraint. Layout-intensive options – including the use of standby treatment capacity – may not be feasible. In such conditions, non-treatment options could be leveraged to help promote reliability and availability including the provision of alternate disposal and supply options. The lack of treatment redundancy may also drive the inclusion of enhanced monitoring to provide a rapid indication of any excursions in treatment.

On the other hand, a site that is required to treat all of its wastewater with no alternate disposal option, or a site that relies exclusively on ONWS for toilet flushing would need to include design elements to ensure a high degree of system availability. In this case, the inclusion of standby units and treatment redundancy may be justified to achieve a high level of reliability and availability.

All projects will need to balance design based on their constraints related to site layout, costs, staffing availability, energy, and access to alternate disposal and supply options.

4.4 Designing Multiple Barrier Treatment Trains

As with all designs, ONWS systems should be designed based on the water quality and treatment goals needed to transform a wastewater source into a safe non-potable supply.

Pathogen Control
In the case of ONWS, the Expert Panel has already established pathogen reduction requirements with the LRTs. As discussed in Chapter 3, pathogen crediting is a key factor in selecting and sizing unit process in an ONWS system.

Monitoring
In addition to the LRT requirements, the Expert Panel also emphasized the importance of monitoring to ensure the continuous performance of the treatment system. Their report identified the desire to switch away from end-point (e.g., effluent) monitoring in favor of online, high-frequency monitoring of surrogates of unit process performance[6]. The specific monitoring requirements are frequently tied to crediting (as described in Chapter 3) with most frameworks using surrogate parameters (e.g., turbidity) rather than through the direct measurement of pathogens (e.g., *Giardia* cysts). The Expert Panel also noted that monitoring requirements may vary for different unit processes. Highest priority is assigned to the monitoring of barriers where LRT crediting will be achieved.

The unit processes in the treatment train that are important for the control of public health concerns – like pathogens – are considered LRT compliance points. To use a common example, chlorine disinfection could be used as a control measure for virus. To ensure that the system is working on a continuous basis, online surrogate parameters of process performance would provide better control than intermittent sampling of virus concentrations in the effluent. In this case, appropriate performance surrogates would be (a) chlorine residual and (b) contact time in order to determine whether the disinfection CT value achieved aligns with the desired degree of virus inactivation.

The benefit of continuous surrogate monitoring is that the performance of the system can be monitored in real- or near real-time. This level of monitoring opens the door to higher degrees of automated control since the system itself can assess performance and make operational

[6] Existing U.S. regulations typically include a combination of both surrogate monitoring and end-point monitoring. Other frameworks – including the Hazard Analysis and Critical Control Point, or HACCP – rely strictly on unit process performance monitoring, and eliminate the need for effluent monitoring.

changes in response to variations in treatment. This is of interest for onsite systems given that many of them will not be staffed full-time by specially trained Operators, but more often operated remotely.

Because pathogen control is the most critical treatment goal, there should be greater emphasis on measuring the performance of barriers that control pathogens. Nevertheless, it is also important to confirm that the other processes are functioning as designed. Biological treatment, for example, may not be an explicit pathogen barrier, though it serves a critical role in the reduction of BOD, TSS, color, and odor. Consequently, Design Engineers should include monitoring that allows operations staff to determine the proper functioning of these types of barriers as well. The selection and frequency of monitoring should be developed and discussed with Regulators during the permitting of the system, but should never be less than the minimum needed by the Design Engineers and Operators to ensure proper system functioning.

Other Water Quality Issues

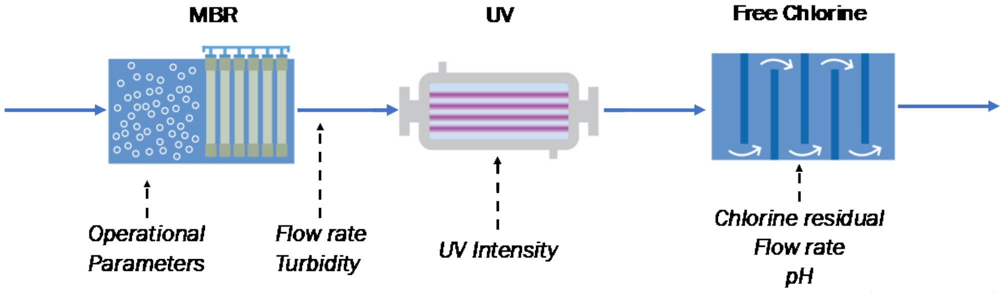
Besides pathogens, there will frequently be other water quality goals that help drive design and unit process selection. For example, many ONWS programs will likely also include requirements for the removal of particulates (e.g., turbidity and total suspended solids), the biological stabilization of the water (e.g., removal of biodegradable organics), and the removal of constituents that cause color and odor (i.e., aesthetics). Aesthetics is an important issue impacting the public acceptability of the recycled water. Water that is turbid, off-colored, or malodorous may lead to public opposition even if the water is demonstrably safe. Consequently, multiple barrier treatment trains must consider additional water quality characteristics including control of organics and turbidity that can lead to aesthetic issues. Treatment processes that provide control against these aesthetic concerns may also be mandatory to prepare the water for downstream treatment processes like disinfection. For example, many validated UV reactors have a window of acceptable influent water quality that may necessitate upstream treatment to remove organics (e.g., BOD) and particulate matter (e.g., turbidity). While these processes alone may not be barriers against pathogens, their inclusion and proper functioning within the treatment train is often a necessary condition for overall treatment success.

4.5 Example Multiple Barrier Treatment Trains

Multiple combinations of unit processes could be used to meet the pathogen LRTs and water quality requirements for ONWS. This section provides sample treatment trains for various source waters and the rationale for their selection.

Blackwater Treatment Train

The sample blackwater treatment train meets the LRT goals through the use of MBR, UV disinfection, and free chlorine disinfection (Figure 22).



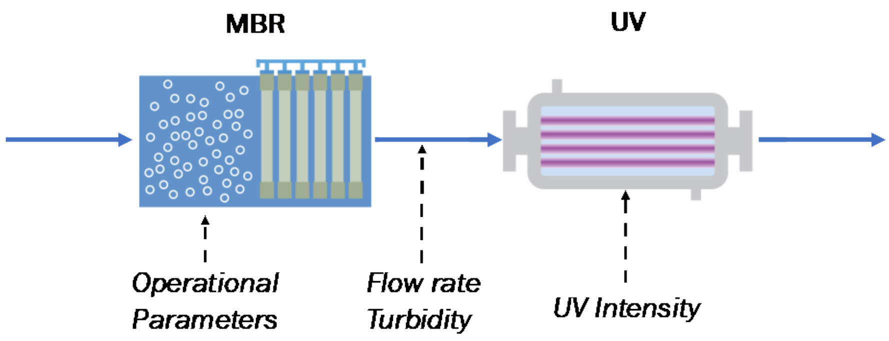
	Unit Process Pathogen Credits			Total Log Removal	LRTs for Blackwater
	MBR	UV	Free Chlorine		
Virus	1.5	3.5	5.0	10.0	8.5
Protozoa	2.0	6.0	0.0	8.0	7.0
Bacteria	4.0	3.5	5.0	12.5	6.0

Figure 22. Example Blackwater Treatment Train.

This train utilizes three treatment barriers that provide a diversity of treatment and contaminant reduction mechanisms. A biological treatment process is included to address the high degree of organic loading from the source blackwater. The MBR provides both biological treatment for the reduction of organic material as well as membrane filtration to remove particulates (both turbidity and TSS). Log reduction crediting is based on compliance with the Australian crediting framework for MBR. MBR pre-treatment creates a high-quality effluent (high UVT, low turbidity) for the downstream UV disinfection process. UV log reduction crediting is based on the use of a validated reactor providing a UV dose of at least 80 mJ/cm^2. Additional crediting is required to comply with the virus and bacterial LRTs; free chlorine disinfection provides the final log credits for these pathogens. The use of *free* chlorine disinfection (as opposed to chloramine) is dependent on the feed water being essentially free of ammonia. The MBR would need to be designed and operated to provide a high degree of nitrification to ensure the effectiveness of the free chlorine process. Virus inactivation credit in this context is based on previous studies evaluating virus disinfection in nitrified, tertiary recycled water.

Graywater Treatment Train

The sample graywater treatment train meets the LRT goals through the use of MBR and UV disinfection (Figure 23). Because graywaters have the potential to contain significant concentrations of organics (i.e., BOD), the treatment train includes a biological process (MBR). As with the blackwater train, the MBR provides a high-quality effluent suitable for UV disinfection, i.e., high UV transmittance and low turbidity. The UV reactor is designed for 150 mJ/cm^2 providing 6-log credits for all pathogen groups. Given this UV design, free chlorine disinfection is not required downstream, though a disinfectant residual will be needed to comply with any requirements for maintaining microbial stability in the distribution system.



	Unit Process Pathogen Credits		Total Log Removal	LRT for Graywater
	MBR	UV		
Virus	1.5	6.0	7.5	6.0
Protozoa	2.0	6.0	8.0	4.5
Bacteria	4.0	6.0	10.0	3.5

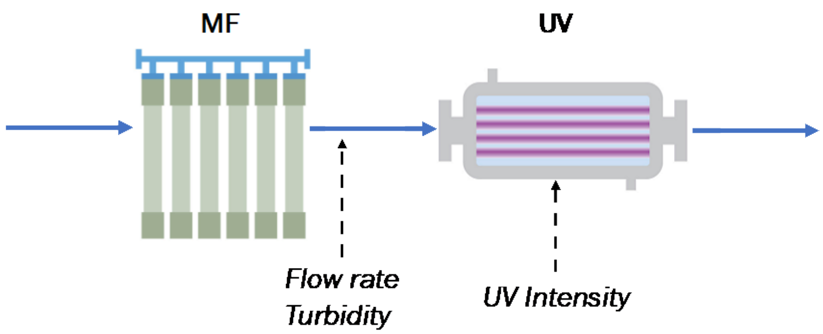
Figure 23. Example Graywater Treatment Train.

Stormwater Treatment Train

The stormwater treatment train meets it treatment goals through the use of both a filtration and disinfection step (MF and UV), though it only receives LRT credits for UV disinfection (Figure 24). The UV system is designed to provide a dose of 80 mJ/cm^2 that allows it to meet the most challenging of the pathogen LRTs: 3.5-log reduction of virus. By providing that dose, the system can also meet the 3.5- and 3.0-log requirements for protozoa and bacteria.

In this case, a filter is provided upstream of the UV system to produce a suitable feed water that is low in suspended particulate material. The governing ONWS jurisdictions may specify turbidity limits for filtration processes prior to disinfection, which would necessitate the use of a turbidimeter downstream of the filter, even if the filter is not receiving LRT credit.

This system does not provide biological treatment based on the assumption that the stormwater will not contain significant amounts of organics that would impact the train’s ability to comply with effluent BOD requirements. This assumption is also critical to ensure a sufficiently high UV transmittance for the UV feed water. The Project Team should collect water quality data on the source stormwater to ensure that the BOD assumptions are justified. Given the intermittent nature of stormwater, water quality measurements should be taken frequently during the first year's wet weather season in order to characterize the range of values. The presence of high BOD levels may impact the ability of a MF and UV system to comply with all of the water quality requirements, including UVT into the UV reactor, final effluent BOD, and minimum chlorine residuals in the distribution system.



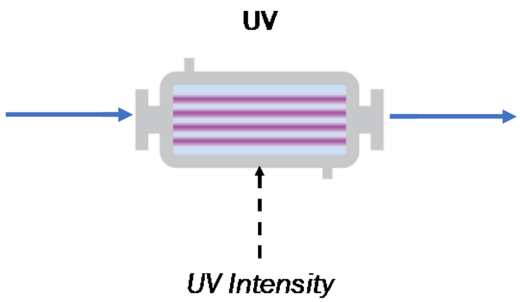
	Unit Process Pathogen Credits		Total Log Removal	LRT for Stormwater
	MF	UV		
Virus	0.0	3.5	3.5	3.5
Protozoa	0.0	6.0	6.0	3.5
Bacteria	0.0	3.5	3.5	3.0

Figure 24. Example Stormwater Treatment Train.

As with the graywater train, a secondary disinfectant residual may be necessary (depending on the governing ONWS rules and regulations) for controlling microbial growth in the distribution system.

Roof Runoff Treatment Train

Given the higher quality of the source water, only a single unit process may be needed for the treatment of roof runoff. In this example, a UV reactor designed to provide 80 mJ/cm^2 provides sufficient disinfection to meet the 3.5-log bacterial LRT (Figure 25).



	Unit Process Pathogen Credits	Total Log Removal	LRT for Roof Runoff
	UV		
Virus	N/A	N/A	N/A
Protozoa	N/A	N/A	N/A
Bacteria	3.5	3.5	3.5

Figure 25. Example Roof Runoff Treatment Train.

As previously stated, UV crediting may also be contingent on the source water quality in terms of UV transmittance and turbidity. If turbidity limits are imposed, an additional turbidimeter would be needed on the UV influent.

4.6 Other Design Considerations

There are a number of other design considerations that are both generally applicable to all sites and others that are particularly relevant to the specific constraints of ONWS systems – see Table 21 for more information.

Table 21. Summary of General Design Considerations.

System Element	Design Recommendations
Sample locations	During design of the facility, the Design Engineer should take sample locations into consideration ensuring that they are easily accessible and near drain locations. Sample taps before and after treatment steps provides optimum flexibility to assess performance through the unit processes. Additional information on operator access and process drainage considerations is provided in the Washington State Department of Health reference included in the additional resources section.
Meter and sensor selection	Instruments selected during design must be appropriate for the water quality of the application. For example, some instruments designed for use in drinking water systems may not be appropriate for blackwater or graywater. Higher concentrations of solids and organics can make instrument maintainability more challenging and can impact the accuracy of readings. These issues should be taken into account, particularly if the instrument is used to assess an LRT compliance point or the data are reported to the regulatory agency. Meters with proven track records in wastewater applications should be considered for black- and graywater.
Hydraulic profile	Design Engineers should pay attention to hydraulic profile considerations given that ONWS systems may be distributed across a building floor or located on multiple floors in a building.
Serviceability	Given the space constraints in ONWS settings, Design Engineers should ensure that sufficient access is provided to warrant serviceability of the process train. For example, sufficient space should be provided to gain access to tank covers and for the removal and replacement of equipment (e.g., MF and RO elements).
Miscellaneous	Other topics warranting further attention include 1) the compatibility of the materials of construction with the site, and 2) air handling considerations particularly for processes producing potentially dangerous off-gases.

4.7 Summary of Developing Multiple-Barrier ONWS Systems

The goal of Chapter 4 is to introduce the concept of a multiple-barrier approach to designing treatment trains for ONWS systems. It was demonstrated that one treatment process will most likely not be able to meet the required LRTs for pathogen control, or all of the goals for general water quality. The chapter then described various approaches to address this challenge through multiple treatment barriers that provide robustness and redundancy. This approach has important benefits including (a) ensuring the reliable production of safe water, and (b) increasing the uptime of the system to maximize the investment and use of the non-potable supply. The concept of non-treatment (i.e., management) barriers was also introduced and described, including source control, alternative disposal and supply options, flow equalization, monitoring, and operational optimization. These non-treatment barriers can promote the goals of public health reliability and system availability.

Chapter 4 also describes the key design aspects that should be considered – pathogen control, monitoring, and other water quality issues – and how they can be addressed through design decisions. Treatment design examples are shown to illustrate how a Design Engineer can employ the concepts of multiple barriers as they design ONWS treatment systems. This discussion includes treatment design examples for all of the key source water types (blackwater, graywater, stormwater, and roof runoff), and shows how each treatment trained achieved the required LRTs.

4.8 Additional Resources

EPA (1989) Surface Water Treatment Rule. 40 CFR 141.70-141.75. Washington, D.C.

Pecson, B.M., Trussell, R.S., Pisarenko, A.N., and Trussell, R.R. (2015) Achieving Reliability in Potable Reuse: The Four Rs. *Journal American Water Works Association*, 107 (3), 48-58.

Regli, S., Rose, J.B., Haas, C.N., and Gerba, C.P. (1991) Modeling the risk from Giardia and viruses in drinking water. *Journal American Water Works Association*, 83 (11), 76-84.

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H., and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

Washington State Department of Health (2018) Monitoring surface water treatment processes. DOH Publication 331-620.https://www.doh.wa.gov/Portals/1/Documents/Pubs/331-620.pdf.

5 Operations Plan

This chapter addresses the key learning objectives for the Design Engineer, Regulator, and Operator with regard to the Operations Plan. The specific learning objectives for this chapter are shown in Figure 26.

Chapter 5 Key Learning Objectives	
DESIGN ENGINEER	• Importance of interface between design, permitting, and operations • Role in start-up and commissioning of ONWS systems
REGULATOR	• Importance of interface between design, permitting, and operations • Documents for operations, reporting, commissioning, and worker safety • Role in start-up, commissioning, and ongoing monitoring of ONWS systems
OPERATOR	• Importance of interface between design, permitting, and operations • Role in start-up, commissioning, and ongoing operations of ONWS systems • Documents for operations, reporting, commissioning, and safety • Staffing needs for ONWS systems
PROGRAM ADMINISTRATOR	• Important documents for operations, reporting, commissioning, and worker safety

Figure 26. Chapter 5 Key Learning Objectives.

This chapter presents recommendations and considerations for the operation of ONWS systems. The primary goal of ONWS systems is to provide safe treated water for the end users by meeting or exceeding all compliance objectives, maintaining reliability and uptime of the equipment to maximize the use of treated ONWS water, and ensuring the safety of all operating personnel.

The Operations Plan for the ONWS system is a critical part of a successful project because it documents all of the key components for operating and maintaining the system. The manual should be developed by the Design Engineer and/or system integrator with input from equipment manufacturers, Operators, and the System Owner. Typically, an electronic Operations Plan is readily accessible from a computer workstation and loaded on mobile devices (e.g., tablets and smartphones) at the ONWS facility with a back-up hard copy available, as well. Essential elements of an Operations Plan include, at a minimum:

- Operations and Maintenance (O&M) Manual
  - Compilation of equipment O&M manuals
- Process Design and Control Theory
  - Process Control
  - Performance Monitoring
  - Alarms and Notifications
  - System Design Criteria
  - Installation Instructions
  - Control Narrative
  - Bill of Materials
  - As-Built Process, Mechanical, and Electrical Drawings
- Standard Operating Procedures
  - Detailed Startup and Shutdown Procedures
  - Operator Log Sheets and Checklists
  - Troubleshooting Procedures
- Maintenance Plan
  - Maintenance Recommendations and Frequencies
  - Spare Parts Recommendations
  - Component Technical Cut Sheets
- Compliance Reporting
  - Sampling and Reporting Requirements
- Environment, Health and Safety Plan
  - Safety protocols
  - Personal protective equipment
  - Security Measures
  - Key Contact Information
- Emergency Response Plan
  - Contingency Plan (e.g., supplement with alternative water sources)
  - Key Contact Information
- O&M Staffing Plan
- Commissioning and Acceptance Test Plan
- Process Optimization

The following sections of this chapter describe some of these key elements of operating and maintaining an ONWS system.

5.1 Process Design and Control Theory

The following sections describe the critical components of the Process Design and Control Theory of an ONWS system including how the process is supposed to function, which aspects of the process should be monitored to maintain functionality, and what parameters should have setpoints and alarms to alert operators of when the system isn't performing properly.

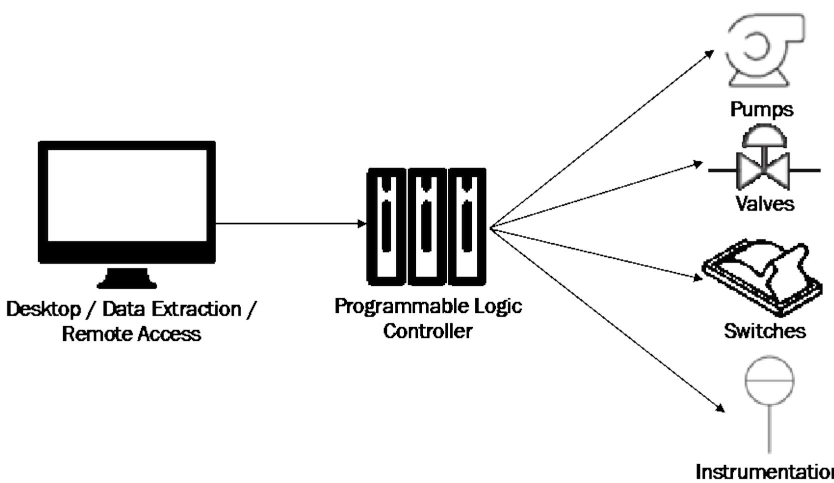
Process Control

Understanding the control philosophy of the system is critical for successful ONWS system operation. This is typically described in the Control Narrative section of the Operations Plan. Some of this information will be provided by equipment manufacturers and other information will be developed by the Design Engineer. The information needed to define a process's control is:

- Description of operating modes (e.g., normal, standby, cleaning, etc.).
- Sequence of events for each mode of operation.
- Identification and description of instrumentation used for monitoring and control.
- Identification of operational setpoints, alarms, and feedback controls.

Process control typically involves the use of programmable logic controllers (PLCs) that are connected to various components of the system, such as pumps, valves, switches and instruments. The PLC is programmed to execute instructions based on feedback from the online monitors to maintain the system in the desired range of operating conditions. The PLC can be connected to interfaces through which Operators can see process performance data, modify operational setpoints, and initiate actions like cleans, diversion, and shutdowns.

Performance Monitoring



One element that is critical for process control is the online instrumentation used for process monitoring. The Control Narrative should identify the monitors used for a) assessing LRT compliance, b) assessing water quality compliance, and c) maintaining stable operations. Each monitor should have an associated acceptable operating range identified in the Operations Plan. This range could be based on achieving treatment compliance (e.g., acceptable UV transmission range for UV disinfection), maintaining production (e.g., transmembrane pressure on a membrane filter to signal the need for backwashing), or preventing equipment damage (e.g., measuring free chlorine residuals upstream of RO membranes). A Quality Assurance Project Plan should also be developed to ensure that a) the water quality samples that are collected and analyzed, b) the data that are stored and managed, and c) the monitoring reports are of sufficient quality to meet project needs.

Alarms and Notifications

Some key monitoring parameters will have a setpoint, which is a target value or range that can be controlled through the modification of operating conditions. A common parameter that has a setpoint is a disinfectant residual, such as free chlorine. The dosing of the chemical can be adjusted automatically by the control system based on the monitored residual value and flow rate in order to maintain a specified value or range. The Control Narrative should include all setpoints and associated feedback mechanisms to ensure the targets are met.

Processes that operate outside of their operating ranges or fail to meet their setpoints should generate alarms that either initiate an Operator response to restore the process to stable operation or result in an automated response. The most important types of alarms for ONWS fall into three categories: LRT compliance, water quality, and operational alarms. Alarms can be associated with varying levels of criticality. **"Alert" levels** could be used to indicate minimal system impacts and provide opportunities for corrective action to be taken before the issue escalates. **"Critical" alarms** indicate severe impacts to the system in terms of either compliance or production, and must be tied to automated responses such as diversion or shutdown. The required action for various operational or treatment issues should be discussed with the Regulators. Any issue resulting in a critical alarm should be resolved prior to returning to normal operations.

The Control Narrative should identify all alarm levels and describe the automated system response or required Operator intervention for both "alert" and "critical" level alarms. A sample table of alarms is provided in Table 22.

Table 22. Examples of Alarm Information for Select Treatment Processes.

Location	Alarm Name	Alarm Type	Alarm Level	Response
Cartridge Filter	High effluent turbidity (NTU)	Water Quality	**Alert:** 0.2	**Alert:** Operator visually inspect for signs of integrity breach.
			Critical: 0.5	**Critical:** Automated diversion to sewer.
UV	Low influent UVT (% UVT)	LRT Compliance	**Alert:** 80%	**Alert:** Operator inspect upstream process data for indications of performance deteriorating.
			Critical: 75%	**Critical:** Automated diversion to sewer.
Treated Water Tank	Low chlorine residual (mg/L)	Water Quality	**Alert:** 0.7	**Alert:** Operator verify residual reading and check chlorine dosing pump.
			Critical: 0.5	**Critical:** Automated diversion to sewer.

5.2 Standard Operating Procedures

An SOP is a set of step-by-step instructions developed to help Operators carry out complex or routine operations. The goal of an SOP is to achieve efficient and consistent performance while reducing miscommunication and failure to comply. SOPs are typically developed by the Operators themselves (so they are suited to the skill level of the user) with input from the Design Engineer, system integrator, and equipment manufacturers. SOPs also help to ensure proper knowledge transfer in the event of staff absence or turnover. Some example SOPs for an ONWS system include (but are not limited to):

- Safely filling a chemical storage tank.
- Shutting down the ONWS system.
- Replacing the lamps in a UV reactor.
- Replacing the chemical reagent for a chlorine analyzer.
- Collecting and analyzing water quality samples.
- Equipment calibration.

SOPs should be kept onsite in a location that is easily accessible and identified for all Operators of the system. Electronic versions of the SOPs should also be filed so that if procedures change (e.g., an analyzer is replaced with a different model, a new treatment process is added, system operations are changed through process optimization, etc.), the SOPs can remain current.

5.3 Maintenance Plan

A well-maintained ONWS system will have a condition-based maintenance plan that prioritizes maintenance based on maintaining system reliability and accounting for potential cascading effects from lack of maintenance. Typical levels of maintenance activities include routine maintenance, preventive maintenance, equipment repair, and equipment replacement.

Level 1 - Routine Maintenance

Routine (or daily) maintenance is performed by the O&M staff and includes activities such as monitoring and responding to alarms, reviewing operational logs, performing house-keeping, and conducting walkthroughs of the ONWS system. Online analyzer readings should also be checked and verified per the Operations Plan and SOPs. Buffers and reagents should be refilled as required. If maintenance-related issues are observed, staff should document and circulate to appropriate personnel for scheduling.

> **SYSTEM OWNER**
>
> Successful implementation of the Operations Plan will require that necessary resources – personnel, training, funds, information, infrastructure – are available.

Level 2 - Preventive Maintenance

The best-maintained ONWS systems have O&M staff that favor the practice of preventive maintenance over reactive maintenance. A strong preventive maintenance program reduces overall maintenance costs by decreasing the frequency, cost, and downtime of repairs. Preventive maintenance tasks are performed according to equipment manufacturer requirements and recommendations, unless enhanced or modified suggestions are included based on operating experience. This type of work should be scheduled and tracked, and the results recorded. Results are typically evaluated, and then adjustments are made as required to enhance reliability and reduce risk of failure. Maintenance schedules should be developed for each asset with tasks categorized as Daily, Weekly, Monthly, or Periodic. A Computerized Maintenance Management System is recommended to facilitate this type of program.

Level 3 - Equipment Repair

O&M Staff or authorized service providers should be utilized to perform repair activities when indicated by inspections, readings, or manufacturer recommendations. Repairs should be carried out in a timely fashion and scheduled to reduce interference to operation of the ONWS system.

Level 4 - Equipment Replacement

Replacement of equipment is an activity that is determined based on operational and maintenance data collected over time. These types of activities may be planned, scheduled, and budgeted for via capital expenditures. Replacement of equipment parts, pieces, or assemblies will take place based on design criteria, operational data, inspections, and condition assessments.

Table 23 presents examples of routine operations and maintenance activities for a treatment system consisting of MBR, UV, and chlorine disinfection.

Table 23. Examples of Routine Operations and Maintenance Activities.

Routine Operations and Maintenance Activities	
Daily • Check for leaks and odors. • Check plant status and tank levels are normal. • Check and respond to any alarms or warnings. • Record key operating parameters. • Perform any required grab sampling (e.g., turbidity and chlorine residual). • Check and record chemical levels. • Check for any unusual noises or vibration on equipment.	**Weekly** • Check chemical levels and fill as needed. • Drain condensate from air receivers. • Perform any required grab sampling (e.g., total coliform and BOD). • Check biomass color and MLSS, and any signs of foaming. • Inspect screens for any buildup of debris.
Monthly • Perform service and calibration checks on critical instruments. • Check sludge concentration and condition. • Check mixer and aeration distribution is normal. • Check UV sleeve and lamps, clean sleeves if necessary.	**Periodic** • Perform chemical cleans on membranes. • Replace UV lamps as needed (typically 12-18 months). • Replace or refurbish analytical probes as required.

5.4 Compliance Reporting

Compliance Reporting is a regulatory requirement to ensure that an ONWS system is meeting the conditions of the operating permit. While exact reporting requirements will depend on the permit, a sampling plan should be developed by the O&M staff to detail the frequency, location, type of sample, analytical methods, contact information of the laboratory conducting the analyses, and any other information such as holding times and turnaround times. Additionally, the sampling plan should include a report template per the permit conditions that can be easily filled out and submitted. The type of data that may be required for compliance reporting include:

- Online process data.
- Grab sample analytical results.
- Maintenance records.
- Meter calibration records.
- System events logs.

Data loggers are recommended for online process data and system events logs. Lab reporting software may be helpful for storing, organizing, and transferring grab sample analytical results. A Computerized Maintenance Management System will assist with accessing maintenance records, meter calibration records, and system events logs.

The Design Engineer working with regulator should develop the daily and monthly treatment plant report form(s) that will be required during the design phase of the project. Ideally, compliance and operational reporting needs can be combined in a single report format.

5.5 Environment, Health, and Safety Plan

The purpose of the Environment, Health and Safety Plan is to communicate and implement practices of environmental protection and workplace safety. From a health and safety perspective, it includes complying with OSHA regulations and creating procedures for identifying workplace hazards and reducing accidents and exposure to harmful situations. From an environmental perspective, it involves creating a system approach to comply with environmental regulations such as managing air emissions. Although not explicitly covered in the Environment, Health and Safety Plan, all Operators and personnel working within close proximity of the ONWS system should be trained to have enough understanding to confidently adhere to the plan. The training manuals that accompany this Guidance Manual will provide additional information regarding what information Operators and personnel will need to know to safely interact with the ONWS system.

One essential element of the Environment, Health and Safety Plan for an ONWS facility is chemical safety. A chemical safety plan describes the chemicals stored onsite and how to safely store and handle these chemicals. Safety data sheets (SDS) and a site map of all chemicals onsite should be readily accessible to all O&M staff and any personnel visiting the facility. Records should be maintained onsite per regulatory requirements including weekly hazardous material inspection logs, chemical release assessment and reporting records, and hazardous waste manifests. Additionally, the chemical safety plan includes information described in Figure 27.

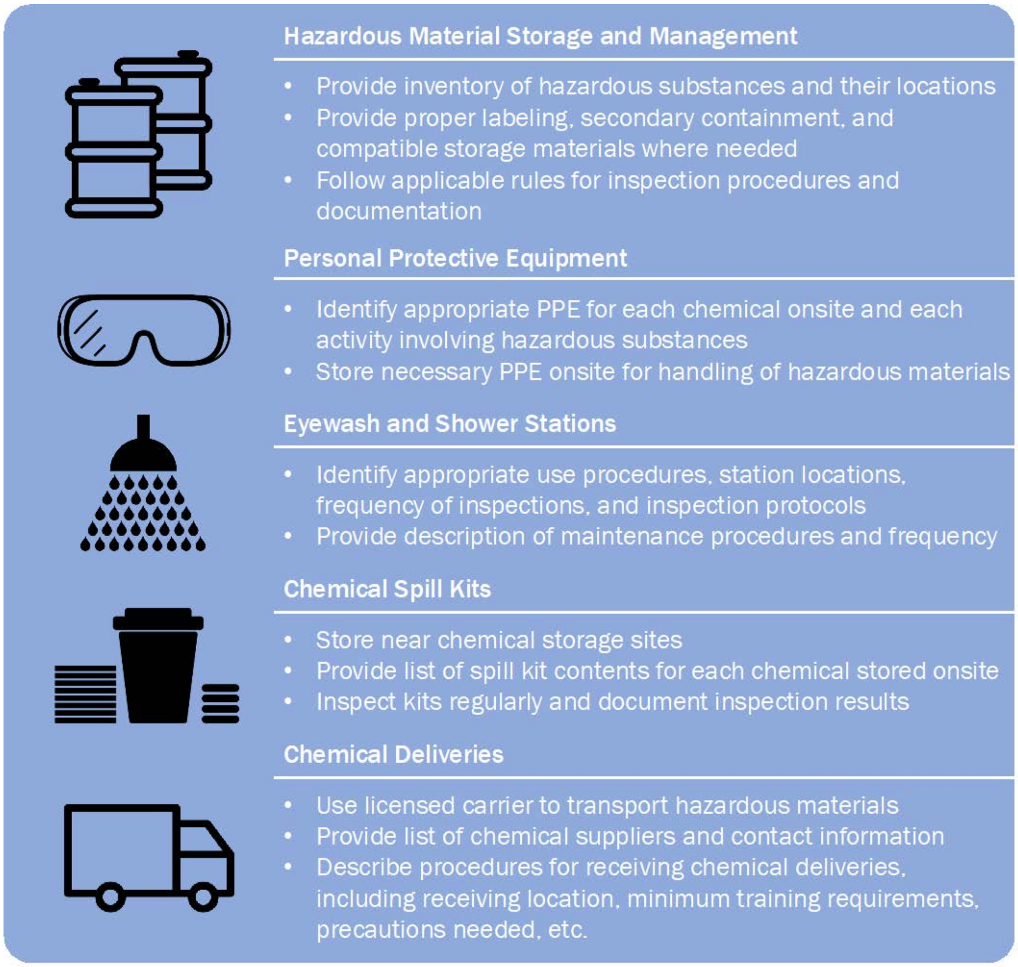


Figure 27. Example of Considerations for a Chemical Safety Plan.

5.6 Emergency Response Plan

The purpose of the Emergency Response Plan is to provide O&M staff, the System Owner, and outside agencies a description of procedures the System Owner intends to implement in the event of localized emergencies affecting the ONWS system facilities and widespread emergencies like natural disasters. These procedures are designed to protect the public, as well as fire fighters and other emergency personnel in the event of an actual emergency at the ONWS system facilities. Key elements of an Emergency Response Plan should include, at a minimum:

- ONWS system Operator/Owner contact information.
- Facility owner contact information.
- Evacuation Plan.
- Emergency Contacts (fire, police, ambulance, poison control center, nearest hospital).

- Post-Incident Contacts (Occupational Safety and Health Administration (OSHA), air quality management district, power utility, water regulator).
- Fire Emergency Procedures.
- Earthquake/Hurricane/Tornado Emergency Procedures.
- Bomb Threat Response.
- Hazardous Material Incidents Plan.
- Power Outage.
- Natural Gas Leak.
- Personal Protective Equipment Program.
- Injury Report.

5.7 O&M Staffing Plan

An O&M Staffing Plan should be developed well before commencement of start-up. This O&M Staffing Plan should address the following key questions:

1. **How many hours per day or week are onsite staff needed to support the ONWS system?**

   This will depend upon the degree of automation designed into the system, the maintenance requirements of all the equipment, sampling requirements for regulatory compliance, and the ability to use remote monitoring and control for routine operations. It is unlikely that an ONWS system will be staffed onsite 24 hours per day and seven days per week; however, it is plausible that an ONWS system will be staffed onsite eight hours per day and five days per week. The most likely scenario for ONWS systems is that staff make routine daily checks onsite, continuously monitor the system remotely (including being notified of alarms), be available to respond to alarms or emergencies, and schedule visits for planned maintenance and sampling activities.

2. **What type of staff are needed to both operate and maintain the ONWS system?**

   Staff requirements may vary by jurisdiction; projects should check local requirements. If the system utilizes biological treatment, it is recommended that there be at least one operator on staff with specific training for this process. Additionally, full-time, part-time, on-call, or service contractors may be used to serve the needs of an ONWS system including day-to-day operations, general maintenance, sampling, and instrumentation and controls. Special consideration should be given to technical support for instrumentation and controls, as highly automated systems tend to be more complex and have a significant number of instruments that need to be serviced and maintained. San Francisco's ONWS program also requires that a Treatment System Manager be identified. This manager must sign an affidavit attesting that she or he has the knowledge, skills, abilities, and training to operate and manage the ONWS system. Minimum requirements for this manager are also specified for certain applications (e.g., blackwater and graywater).

3. **What type of training do staff need to successfully operate the ONWS system**?

   Training should be provided to all staff that will be engaged in supporting the ONWS system. Typically, initial training will be provided by the system integrator and/or equipment manufacturers along with the Design Engineer. A combination of classroom and hands-on training are effective methods with periodic refreshers. Trainers should provide training materials to staff that augment the O&M Manual, SOPs, Health and Safety

Plan, and other essential documentation. The training modules, which accompany this Guidance Manual, will cover topics ranging from regulatory to design to operations. These modules can be used as a foundation for developing an operator training program and include a deeper discussion on operations planning. However, there is an assumption in both this Guidance Manual and the accompanying training modules that operators will have some level of prior experience with water and wastewater treatment.

5.8 Commissioning and Acceptance Test Plan

While the Operations Plan should include a detailed description of the startup procedures for each individual unit treatment process and the overall ONWS system, a Commissioning and Acceptance Test Plan should describe specific procedures to be conducted to ensure that both design and performance specifications are met including regulatory compliance. This test plan should also detail when the commissioning will take place (typically after initial startup and major system changes), and the anticipated duration of the commissioning and acceptance testing. Developing a Commissioning and Acceptance Test Plan provides documentation of the system performance expectations. It is also good business practice because it compels the system integrator and equipment manufacturer to demonstrate all contractual requirements prior to acceptance by the System Owner and Operators. Additionally, Regulators may require both approval of a Commissioning Test Plan, along with the demonstration of regulatory compliance prior to granting Permit to Use that will allow the delivery of treated water for reuse.

Example Commissioning Test Plan Checklist

Commissioning Test Plan Checklist

- ☐ Set up system to ensure all treatment processes receiving pathogen credit can be sampled
- ☐ Ensure treated water can be discharged safely, e.g. to sewer
- ☐ Ensure adequate chemicals and consumables are available
- ☐ Notify relevant agencies about test plan and schedule
- ☐ Verify system controls are effective for ensuring LRT compliance, for example:
  - ☐ *Low UVT alarm*
  - ☐ *Low chlorine residual alarm*
  - ☐ *High turbidity alarm*
  - ☐ *Other critical LRT compliance alarms*
- ☐ Provide results to relevant agencies

5.9 Process Optimization

As with any advanced treatment system, multiple opportunities will exist for the ONWS system to be optimized during and/or after start-up. Optimization has many benefits including continued Operator ownership in the performance of the system, reducing energy and chemical usage, reducing operating costs, improving reliability, and further ensuring regulatory compliance to protect public health. Optimization may require conducting tests (sampling, adjusting operating conditions, etc.) above and beyond the routine requirements of the Operations Plan and Compliance Report. Some examples of Optimization for an ONWS system include (but are not limited to):

- Tuning a control loop to prevent overdosing of chlorine.
- Determining the optimal frequency to change a cartridge filter based on effluent turbidity and pumping costs (due to head loss) versus loss of production.
- Adjusting the operation of the secondary biological treatment system to reduce organic loading on the membrane filter and thus reduce the rate of fouling.

Regular observation and trending of operational data is extremely valuable as a tool for optimization. This is most easily accomplished using HMI/SCADA historian technology or data loggers. Evaluating operational (and performance) data over time allows O&M staff to identify concerning trends, spot unexpected changes, and determine causation between certain system factors. For example, monitoring the transmembrane pressure drop of a membrane filtration system over time will allow Operators to determine if the current regime of backwashing and cleaning cycles is effective at restoring the original performance of the membranes as efficiently as possible.

5.10 Summary of Operations Planning

The goal of Chapter 5 is to introduce the key components of operating and maintaining an ONWS system and to describe the tools needed to ensure a safe and well-functioning system. The components discussed include a description of the typical information included in an Operations plan, such as considerations for documenting process design and control theory, parts of an SOP, developing a staffing plan, components of a Commissioning and Acceptance Test Plan, and optimizing ONWS operations.

By examining the breadth of concepts – from safety to performance optimization – it's clear that extensive effort and organization is required to operate ONWS systems. Although it is important to operate and maintain the system to ensure production of safe water, it is equally important to create a safe and healthy environment for the operators and personnel who interact with the system. This chapter introduces the key tools that can be used to achieve both of these goals.

5.11 Additional Resources

O&M Manual Template

San Francisco Department of Public Health (2018) Alternate Water Source System Operations and Maintenance Manual Template. https://www.sfdph.org/dph/files/EHSdocs/ehsWaterdocs/NonPotable/Alternate_Water_Source_System_OandM_Manual_Template.dot.

Reporting Template

National Blue Ribbon Commission for Onsite Non-potable Water Systems (2017). A Guidebook for Developing and Implementing Regulations, Technical Appendix. Appendix D: Sample Reporting Documents. http://uswateralliance.org/sites/uswateralliance.org/files/NBRC%20GUIDEBOOK_APPENDIX_FINAL.pdf.

6 Regulatory and Permitting Plan

This chapter addresses the key learning objectives for the Design Engineer, Regulator, and Operator with regard to the Regulatory and Permitting Plan. The specific learning objectives for this chapter are shown in Figure 28.

Chapter 6 Key Learning Objectives	
DESIGN ENGINEER	• Typical steps in the regulatory process • Key documents needed from Design Engineers for permitting • Importance of interactions with the Regulators
REGULATOR	• Typical steps in the regulatory process • Key documents needed from project team for permitting including startup, commissioning, and compliance • Importance of interactions with the project team
OPERATOR	• Typical steps in the regulatory process • Key documents needed for compliance • Importance of interactions with the Regulators
PROGRAM ADMINISTRATOR	• Typical steps in the regulatory process • Importance of interaction between Regulators and the project team

Figure 28.Chapter 6 Key Learning Objectives.

An effective permitting process provides Regulators (and Program Administrators) multiple opportunities to evaluate projects and ensure compliance with ONWS requirements. Input from Regulators helps to ensure the success of ONWS programs by promoting communication with the project staff responsible for the design, construction, and operation of the facility. As described in Chapter 1, there are multiple steps necessary to implement an ONWS program. The specific details of the program may differ from jurisdiction to jurisdiction, but will likely entail many of the elements offered in the Commission's *Guidebook*. It is also important to note that multiple Regulators with varying jurisdictions may be needed for permitting (e.g., regulators at health departments, building inspectors, etc.). Figure 29 provides an example of possible steps in this process and the interactions between the **Project Team** (e.g., System Owners, Design Engineers, and Operators) and the **Regulators**.

Regardless of the specific steps of an ONWS program, early and frequent communication between the Regulators and other stakeholders is important to ensure the ONWS project meets all of the Regulators' permitting requirements. The risk-based ONWS framework described in this Guidance Manual emphasizes monitoring system performance, and so communication between the Regulator and other stakeholders should include discussions regarding all aspects of the ONWS project, including key design decisions as well as expectations for ongoing monitoring and reporting, as these decisions may impact the design. Early communication between the Regulator and other stakeholders regarding project design and monitoring requirements can streamline the process outlined in Figure 29.

PROJECT TEAM	REGULATOR
INITIAL PROJECT DEVELOPMENT	
• Project Application	• Review and approve Project Application
PRELIMINARY DESIGN	
• Engineering Report (Preliminary)	• Review Preliminary Engineering Report
FINAL DESIGN, CONSTRUCTION, AND INITIAL INSPECTIONS	
• 100% Design • Engineering Report (Final) • Operations and Maintenance Plan including Commissioning Plan • Construction • Cross-connection inspection	• Permit to Operate
PROJECT STARTUP	
• Commissioning	• Installation inspection • Permit to Use
ON-GOING MONITORING AND REPORTING	
• On-going monitoring and reporting	• Performance and water quality data review • Inspections and enforcement • Periodic permit renewal

Figure 29. Example Steps of the Regulatory and Permitting Process for an ONWS System.
Steps may vary by jurisdiction.

Using this framework, ONWS projects can be divided into five stages:

- Initial Project Development.
- Preliminary Engineering.
- Final Design, Construction, and Initial Inspections.
- Project Startup and Commissioning.
- Ongoing Monitoring, Reporting, Inspection, and Enforcement.

This chapter walks through each of these stages and describes the type of information required, the level of detail necessary at each step, and the roles of both the Project Team and Regulatory staff in the process. The goal of this chapter is to provide both **Regulators** and the Project Team (**System Owners**, **Design Engineers**, and **Operators**) a regulatory roadmap for developing and operating a successful ONWS project.

The chapter has an emphasis on compliance with the LRT framework, but discusses other regulatory considerations as well. Certain elements of the permitting process will not be covered in detail here, such as water budgets/calculators that may be needed to determine source water availability and non-potable demands, cross-connection testing, or plumbing plan inspections. Chapter 1 provides a high-level overview of ONWS implementation that includes these steps and additional resources are presented at the end of this chapter.

6.1 Initial Project Development

Project Application

The first step in the process, the Project Application, provides an opportunity for the Project Team to communicate the basic elements of the proposed project with Regulators. The Project Application should include at a minimum basic information about the ONWS system including:

- System size and location.
- Scale of the system (e.g., building-scale or district-scale).
- Project team roles and responsibilities including System Owner, Design Engineer, and Operator.
- Type of water to be treated (e.g., blackwater, graywater, or rainwater).[7]
- Intended end uses for ONWS water (e.g., toilet flushing and irrigation).

> A website for the ONWS program where all relevant regulatory documents are collected is recommended to facilitate knowledge transfer with project teams.
>
> A sample layout for information sharing can be found at: https://www.sfdph.org/dph/EH/Water/nonPotable.asp.

Through this interaction, the Regulators obtain a high-level understanding of the proposed project and can ensure that the Project Team has access to important resources (e.g., rules and regulations, guidance documents, templates) that can help streamline the subsequent steps in the permitting process. Review and approval by the Regulators can help ensure that the Project Team follows the correct guidelines during subsequent design stages.

[7] The treatment of certain types of water may require interaction with both state and local Regulators.

6.2 Preliminary Engineering

Preliminary Design

After receiving regulatory approval of the Project Application, the Project Team can proceed with the preliminary design of the ONWS system. To foster communication and feedback with the Regulators, it is recommended that the Project Team begin with a preliminary design (e.g., 10-30% design). This allows many aspects of the treatment system to be developed and discussed without requiring the investment of a full design. If possible, it may be helpful to engage operations and maintenance staff for input during the design process. This stage of design is also sufficient for the creation of a preliminary engineering report. The engineering report serves as the document allowing for discussions between the Regulators and Project Team about the ability of the system to comply with the requirements for ONWS.

Engineering Report

In general, Engineering Reports are used to describe how a project will comply with the criteria for their intended application. The same principle holds for ONWS – the Engineering Report will describe how a project meets the relevant local and/or statewide criteria for ONWS in the same way that a municipal recycled water project would use the Engineering Report to show compliance with relevant statewide regulations. Regulators who have not permitted onsite reuse projects can leverage existing permitting frameworks for other applications to provide structure for ONWS permitting.

Project Teams should submit drafts of the Engineering Report at least twice during the permitting process: once at earlier stages of project development (e.g., after 10-30% design) and again at more detailed levels of design (e.g., after 60-100% design). The initial review – like the Project Application – provides the Regulators with a chance to provide an early review and identify any significant issues or necessary modifications. This input helps guide the Project Team as it advances into detailed design, saving both time and effort. Project teams should also maintain regular and frequent communication with regulators throughout the process.

> An ONWS Engineering Report should be developed by (a) a properly qualified engineer with (b) experience in water and/or wastewater who is (c) registered with the relevant state.

Ultimately, the Engineering Report should include sufficient detail so that Regulators can evaluate whether the degree and reliability of treatment are in line with the requirements for ONWS. Table 24 describes proposed sections of the Engineering Report with a description of the pertinent information for each section.

Table 24. Type of Information That Should Be Included in an ONWS Engineering Report.

Project Element	Type of Information Provided
General Information	• Identify all entities involved in the design, treatment, distribution, construction, and operation and maintenance of the facilities. • Describe legal arrangement with roles and responsibilities between the entities. • Identify the treatment system manager, along with manager's qualifications and responsibilities. • Provide organizational chart (as needed). • Provide additional project information, e.g., building size and type, description of uses, types and number of occupants, visitors, and/or employees.
Rules and Regulations	• Identify relevant rules and regulations governing development and use of ONWS system.
Raw Source Water	• Describe the source water for ONWS (e.g., blackwater, graywater, etc.). • Describe the quality (or assumed quality) of source water. • Describe industrial inputs and source control (as needed). • Estimate total daily and/or annual flow of each source water (may be needed to meet water budget or grant requirements).
Treatment	• Develop process flow diagram including tanks, unit processes, monitors, waste streams, diversion locations, overflows to sanitary sewers, potable makeup supply location, backflow prevention devices, sample ports, etc. • Describe unit processes. • Provide design criteria for unit processes. • Define proposed pathogen credit for each group and associated crediting framework. • Define flow rates entering and leaving each unit process. • Describe chemical usage requirements including identification of chemicals used, the point of application, dosing rate, and chemical specifications. • Provide overview of operations and maintenance • Describe solids and residuals handling.
Monitoring and Reporting	• Describe monitoring and reporting program including all monitoring required by relevant rules and regulations. • Include frequency and location of sampling. • Summarize online monitoring capabilities. • Summarize grab sample monitoring locations and frequency. • Describe calibration methods and frequency.

Project Element	Type of Information Provided
	• Identify the alarms that are included, along with the consequences of the alarms with regard to notification of staff or automated responses. • Provide description of Quality Assurance Project Plan to ensure the quality of data collection, management, and reporting procedures.
Supplemental Water Supply	• Describe the source of supplemental water supply. • Describe the quality and available quantity. • Identify backflow prevention and cross-connection control features.
Contingency Plan	• Describe elements used to prevent the delivery of inadequately treated water to users. • Identify conditions requiring diversion of water. • Describe diversion procedures. • Describe plan for notifying users, regulatory agencies, and other relevant stakeholders in the event of failure.
Use Area	• Describe type of use or uses proposed (e.g., irrigation, toilet flushing, etc.). • Provide map of reuse area. • Document cross-connection control procedures. • Describe measures to minimize public contact and other features (as applicable) for the specified end use.

The Engineering Report should provide sufficient information so that the Regulator can determine if the project's design and planned operation will comply with the relevant rules and regulations governing ONWS. Through this review, the Regulator provides feedback about the approach at an earlier phase of the design. The Design Engineer can then make modifications and address the Regulator's comments in the final design.

6.3 Final Design, Construction, and Initial Inspections

Final Design and Engineering Report

After receiving feedback from the Regulators based on the preliminary engineering report, the Project Team will continue to develop and finalize the design for the system. Once sufficient design detail has been developed (typically 60-100% design phase), the Project Team can revise and submit a final Engineering Report. The Regulators should ensure that any significant issues that were identified during review of the preliminary Engineering Report have been addressed by the Project Team. By accepting the Engineering Report, the Regulators signal that the degree and reliability of the treatment system meets the rules and regulations governing ONWS. To aid in this review, the Regulators can review the final design documents including the engineering drawings and specifications.

Operations Plan

The Operations Plan – introduced and described in Chapter 5 – is a document that complements the Engineering Report by providing additional detail on the specifics of the operation, maintenance, and reporting of the ONWS system. This level of detail is not required to approve an Engineering Report, though it is necessary to describe how the system will be operated, maintained, monitored, and reported.

> Operation and maintenance requirements may vary depending on the jurisdiction. For example, in Washington D.C., the stormwater regulation requires a maintenance obligation signed by the owner/operator of the facility in perpetuity. It is also recorded in the deed with maintenance activity requirements.

Chronologically, the Operations Plan is often developed after the Engineering Report (which may be completed at the 60-100% design phase) when many of the final details of the system have been worked out. Given its focus on the *operation, monitoring, and reporting* of the ONWS system, the Operations Plan is the more critical document mediating the discussion between the **Regulators** and **Operators**. Because the operations staff is frequently not involved with the Engineering Report development, the Operations Plan should serve as a stand-alone document and reference. Consequently, there may be a purposeful overlap of certain topics in the Operations Plan with the Engineering Report.

It is important to note that the Operations Plan is not merely a compiled assembly of the operations and maintenance *manuals* for the various unit processes, meters, pumps, and other equipment present on the site. This information is an important element to include, but the goal of the Operations Plan is to provide a holistic plan for the whole system. In this way, the Operations Plan defines acceptable ranges of operation and performance, setting a clear delineation for what type of performance constitutes a violation of the permit. This level of detail is a critical component of the Operations Plan that provides clarity for performance reporting and enforcement by specifying what level of performance is required for system compliance.

The Operations Plan may also serve as the document that describes the start-up and commissioning plan for the ONWS system. This testing allows the Regulators to verify the proper functioning of the system (e.g., demonstrating the alarms, diversion, and shutdown features), and testing the system's reaction to challenging water quality or operational conditions.

Cross-Connection Inspection

The facility should be inspected for cross-connections and the installation of other required features such as backflow prevention devices. Cross-connection inspections may occur during and/or after construction is complete. Multiple inspections may be useful to identify issues before construction is completed. While this topic is not an explicit focus of this Guidance Manual, additional resources on this topic are available at the end of the chapter. Numerous other inspections may also be required to validate construction of the ONWS system, and should be encouraged to facilitate a working relationship between the Project Team and the Regulators and Program Administrators.

Permit to Operate

The first major permitting document is the Permit to Operate the ONWS system. This allows the ONWS system to produce water for use in the start-up and commissioning of the system, but does not necessarily provide immediate authorization for the distribution and use of the water. This permit should be authorized after the Regulators have reviewed and approved the following documents and inspections[8]:

- 100% design of the ONWS system including design drawings and specifications.
- Final Engineering Report.
- Operations and Maintenance Plan, including the start-up and commissioning plan.
- Construction of the ONWS system.
- Cross-connection testing.

An additional item that the Regulators may request is a construction certification letter, signed and stamped by a professional engineer that certifies that the system was constructed in accordance with the Engineering Report and design documents.

With the Permit to Operate in hand, the ONWS Project Team can commence with the start-up and commissioning efforts. The approved Operations and Maintenance Plan should spell out the requirements for this period, including performance testing, installation inspection, challenge testing, and related efforts.

6.4 Project Startup and Commissioning

Installation Inspection

Once the system has been constructed, the various processes and equipment need to be brought online for the first time to verify proper installation, calibration, and function. This functional testing period is often referred to as the project startup. This period may also be used to acclimate processes, such as biological treatment systems. Startup is differentiated from commissioning, which is the period when the fully functioning system is tested to verify that all of the equipment and processes meet the specification of the design.

After project startup, an ONWS system can be inspected by the Regulators to ensure that the system has been constructed and installed in line with the design. This may include multiple items including verifying the following:

- Installation of proper monitoring at the specified locations.
- Use of specified chemicals.
- Installation of correct unit process equipment in order specified in the design.
- Presence of flow diversions.
- Provision of back-up wastewater disposal and supply options (as needed).

[8] The Permit to Operate may come from either the State or Local level, or both, depending on the system and jurisdiction.

Commissioning

Once the system has undergone startup and an installation inspection, it can begin commissioning. Testing that occurs during commissioning should verify the proper functioning of critical system elements, such as the activation of alarms, diversions, and shutdowns, while also showing the ability of the system to continuously meet its design performance for a given period of time. The commissioning period may also serve as a time to optimize the control strategies and perform any necessary challenge tests or tracer studies to verify process performance or design assumptions.

Permit to Use

The Regulators should collect the periodic reports from the ONWS Project Team throughout the commissioning phase. Additional requirements for the Permit to Use could include verification of the capacity of the staff responsible for the operation of the system. For example, the Permit could also be contingent on the receipt of an affidavit signed by the treatment system manager that verifies his or her knowledge, skill, abilities, and training to operate the system in compliance with requirements in the Operations and Maintenance Plan. Assuming the project can meet the minimum commissioning requirements, the Regulators can issue the final Permit to Use. Ongoing monitoring and reporting of the system should be conducted in accordance with the approved Operations and Maintenance Plan.

It should be stressed that beyond the requirements for ONWS, the Design Engineer, Operator, and System Owner should check local and state ordinances to ensure all of the proper permits have been obtained.

6.5 Ongoing Monitoring, Reporting, Inspection, and Enforcement

The final step in the regulatory process is the ongoing evaluation of system performance through the requirements for monitoring and reporting. These requirements should be worked out and specified in the Operations and Maintenance Plan, including which parameters to measure, the frequency and methods for collecting data, and how the data will be analyzed and reported. Updates to the monitoring and reporting plan should be undertaken after any significant modification to the operations or design of the ONWS system.

The Regulators can verify the proper functioning of ONWS systems through multiple mechanisms including the review of periodic performance and water quality monitoring reports. Additional mechanisms include routine inspections and enforcement actions for systems that violate elements of the governing rules and regulations. Defining the types of violations, the associated penalties, and the corresponding reference in the rules and regulations assists with the enforcement and compliance process.

6.6 Summary of Regulatory and Permitting Planning

Chapter 6 describes the key regulatory and permitting steps of developing an ONWS System – from the initial project development through ongoing monitoring, reporting, and enforcement – and discuss the role of the Regulator through each step. This chapter shows that facilitating interactions between the Project Team and the Regulator throughout the development process can streamline the project effort, leading to an efficient process for all parties involved.

Although the specific details of the ONWS program may differ from jurisdiction to jurisdiction, many of the elements discussed in this chapter will still be relevant.

6.7 Additional Resources

Project Application Templates

New York City Environmental Protection. Comprehensive Water Reuse Program Application and Instructions. https://www1.nyc.gov/html/dep/pdf/waterreuse.pdf.

San Francisco Department of Public Health. Application for Permit to Operate an Alternate Water Source System. https://www.sfdph.org/dph/files/EHSdocs/ehsWaterdocs/. NonPotable/SFHC_12C_Application.pdf.

Engineering Report Templates

California Department of Health Services (2001) Guidelines for the preparation of an engineering report for the production, distribution, and use of recycled water. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Documents/Recharge/ERGUIDE2001.pdf.

National Blue Ribbon Commission for Onsite Non-potable Water Systems (2017). A Guidebook for Developing and Implementing Regulations, Technical Appendix. Appendix C: Sample Engineering Report. http://uswateralliance.org/sites/uswateralliance.org/files/NBRC%20GUIDEBOOK_APPENDIX_FINAL.pdf.

San Francisco Department of Public Health (2018) Non-Potable Engineering Report Template. https://www.sfdph.org/dph/files/EHSdocs/ehsWaterdocs/NonPotable/Non-potableEngrRpttemplate.dot.

Cross-Connection and Backflow Prevention

San Francisco Department of Public Health. Water Quality: Cross Control Program. https://www.sfdph.org/dph/EH/CrossFlow/default.asp.

San Francisco Public Utilities Commission (2017) Required Levels of Backflow Protection for Onsite Water Reuse Systems. https://www.sfdph.org/dph/files/EHSdocs/.ehsCross flowdocs/Required_Backflow_Protection_for_Onsite_Water_Reuse_Systems.pdf

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H., and Olivieri, A. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems: Final Report. Alexandria, VA.

University of Southern California (2009) Manual of Cross-Connection Control, 10th Edition. Foundation for Cross-Connection Control and Hydraulic Research (Ed.).

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