National Blue Ribbon Commission
for Onsite Water Systems

WATEREUSE

OPERATION & MAINTENANCE
TRAINING MANUAL FOR

Onsite Non-potable Water Systems (ONWS)

Onsite Water Reuse Operator Training Program 4/24/2026

Acknowledgments

This acknowledgments page must remain the same (i.e., it cannot be edited or deleted) across iterations, regardless of who repurposes the manual. The respective owner can include subsequent acknowledgement pages; however, this original page must remain unchanged.

Acknowledgements

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Table of Contents

How To Use This Manual

This handbook provides a framework to assist water treatment operators in preparing to take either the Entry-level Onsite Non-potable (rainwater, condensate, stormwater) Exam or the Advanced-level Onsite Non-potable (graywater, stormwater, blackwater) Exam. Stormwater is included in both entry and advanced exams. Stormwater treated with membrane filtration is covered under the entry level exam. Stormwater treated with biological treatment is covered under the advanced. Jurisdictions can determine the required treatment technology to meet the stormwater LRTs and decide which exam (or both) to require of operators.

Sections

This handbook is divided into 16 sections. It is broken up into entry-level content and advanced-level content. The advanced-level content is called out in light blue boxes. Additionally, there is localized content specific to a designated location (light purple boxes).

ADVANCED

These sections will highlight advanced information.

Resources and Terminology

Finally, the handbook includes multiple appendices (e.g., glossary, additional resources list) as well as a reference list at the end, providing a deeper dive for those interested.

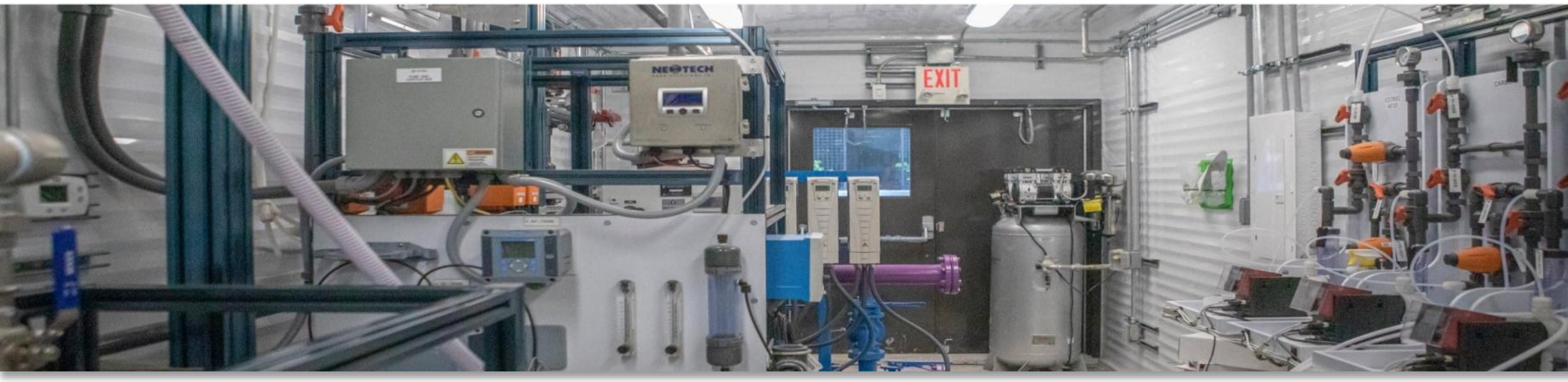
In different municipalities, different terminology will be used. In this handbook, we will use the term onsite non-potable water systems (ONWS), which is interchangeable with the term onsite water reuse systems (OWRS), as used by the City of Austin, Texas.

Uber's headquarters in San Francisco is recycling its graywater onsite *[Photo credit: HTEC]*

Introduction

To address growing pressures on water supplies (such as increased demand, climate change, and impairments to water quality), communities are seeking new approaches to conserve water and develop alternative water supplies. Nationwide, many communities have developed programs to promote or guide the use of onsite water sources for non-potable applications. For example, there are large-scale commercial or multi-residential buildings where sources of water, such as roof runoff, graywater, or domestic wastewater, are collected, treated, and distributed within and around the building for non-potable uses, including toilet flushing and/or landscape irrigation. [WE&RF Final Report p30 para3]

Critical to the ongoing success of onsite non-potable water systems (ONWS) are the availability of an operator workforce (capacity) and sufficient operator training that provides onsite non-potable reuse skill-specific knowledge. The purpose of this handbook is to provide specialized training for operators of onsite non-potable water systems (ONWS) and to impart the specific knowledge necessary for operating and maintaining the types of technologies typically associated with both wastewater and water treatment. [NBRC ONWS Guidance Manual p89 para2-3]



Onsite water reuse treatment system *[Photo credit: Austin Water]*

Section 1
Introduction to Onsite Non-potable Water Treatment

To begin our exploration into the operation of ONWS, let's start by first focusing on the following topics:

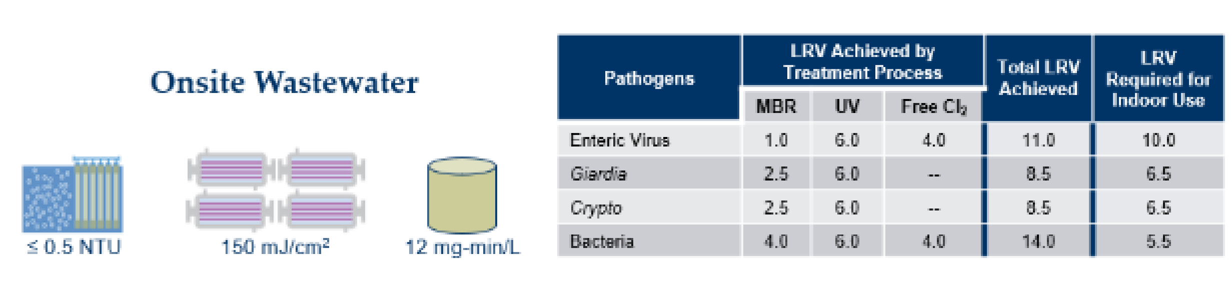
- Public health aspects of onsite non-potable water and goals of safe water for reuse
- Multiple barrier concept
- Types of alternate water sources, end uses, and building types
- Unit processes in onsite water reuse

1.1 Public health aspects of onsite non-potable water and goals of clean water for reuse

One of the most challenging aspects of ONWS is ensuring the appropriate water quality to protect public health. In 2017, the NBRC's landmark report Risk-based Framework for the Development of Public Health Guidance for Decentralized Non-potable Water Systems established a scale-appropriate, risk-based framework for defining and monitoring ONWS treatment systems. Using Quantitative Microbial Risk Assessment (QMRA), the 2017 report centered on risk-based log reduction targets (LRTs) for the treatment of pathogens, including viruses, protozoa, and bacteria. With the report, the NBRC reached a consensus to develop an LRT table for various alternative water sources (using an infection-based benchmark), including combined wastewater or blackwater, graywater, rainwater, and stormwater, for both indoor and outdoor non-potable end uses.

The recommended standard for pathogen removal and/or inactivation requires a treatment train in which unit processes are collectively credited to meet selected LRTs. During operation, the performance of each treatment process is continuously monitored using microbial, chemical, or physical indicator(s) or surrogate parameter(s) that verify their ability to achieve the credited pathogen removal and/or inactivation. Along with the treatment processes required for sufficient log reduction credits, other treatment goals include reducing organics, particulates, and nutrients, as well as delivering aesthetically acceptable water. In addition to establishing LRTs and monitoring requirements, the health risk-based framework includes establishing structures for ongoing regulatory oversight to ensure compliance with ONWS.

The health risk-based framework represents a significant shift from the typical endpoint fecal indicator bacteria monitoring approach commonly used in the United States to determine whether water is suitable for drinking, swimming, or other recreational uses with respect to the risk of infection from microbial contaminants (viruses, protozoa, or bacteria). [NBRC Health Risk-based Benchmarks p5]



Pathogens	LRV Achieved by Treatment Process			Total LRV Achieved	LRV Required for Indoor Use
	MBR	UV	Free Cl_2		
Enteric Virus	1.0	6.0	4.0	11.0	10.0
Giardia	2.5	6.0	--	8.5	6.5
Crypto	2.5	6.0	--	8.5	6.5
Bacteria	4.0	6.0	4.0	14.0	5.5

FIGURE 1.1: *Example treatment train in which treatment processes are credited to meet selected LRTs [San Francisco Public Utilities Commission]*

1.2 Multiple barrier concept

The multiple barrier concept has been utilized in water treatment systems, including ONWS, to ensure reliability and availability. [NBRC ONWS Guidance Manual, p57 para2] It refers to the use of multiple treatment processes to help provide safe water for reuse and increase reliability. No one treatment process addresses all concerns, so using multiple treatment processes becomes necessary, especially for alternative building source waters with higher degrees of contamination (e.g., graywater, blackwater). [NBRC ONWS Guidance manual, p57 para3; p58 para1]

1.3 Types of alternate water sources, end uses, and building types

1.3.1 Types of alternate water sources

This handbook is focused on commercial, mixed-use, and multifamily residential buildings that generate the following types of alternate water sources: [NBRC Utility Case for ONWS, p7 col2 Definition of terms; WWTF3 Ch7 p10 para5; San Francisco Onsite Water Reuse Guidebook p4]

Water Source	Definition
Blackwater or onsite Wastewater	Wastewater originating from toilets and/or kitchen sources (e.g., kitchen sinks, dishwashers), comingled with graywater
Graywater	Wastewater collected from non-blackwater sources (e.g., bathroom sinks, showers, bathtubs, clothes washers, laundry sinks)
Rainwater	Precipitation from rain or snowmelt events collected directly off a roof surface that is not subject to frequent public access
Stormwater	Precipitation runoff from rain or snowmelt events that flows over land and/or impervious surfaces (e.g., streets, parking lots, rooftops); may include runoff from roofs with frequent public access
Condensate	Water vapor that is converted to a liquid and collected; most common sources in buildings include air conditioning, refrigeration, and steam heating
Foundation water	Shallow groundwater collected from drainage around building foundations or sumps

TABLE 1.1: *Potential water sources for an ONWS [WE&RF Final Report p3, San Francisco Onsite Reuse Program Guidebook p2]*

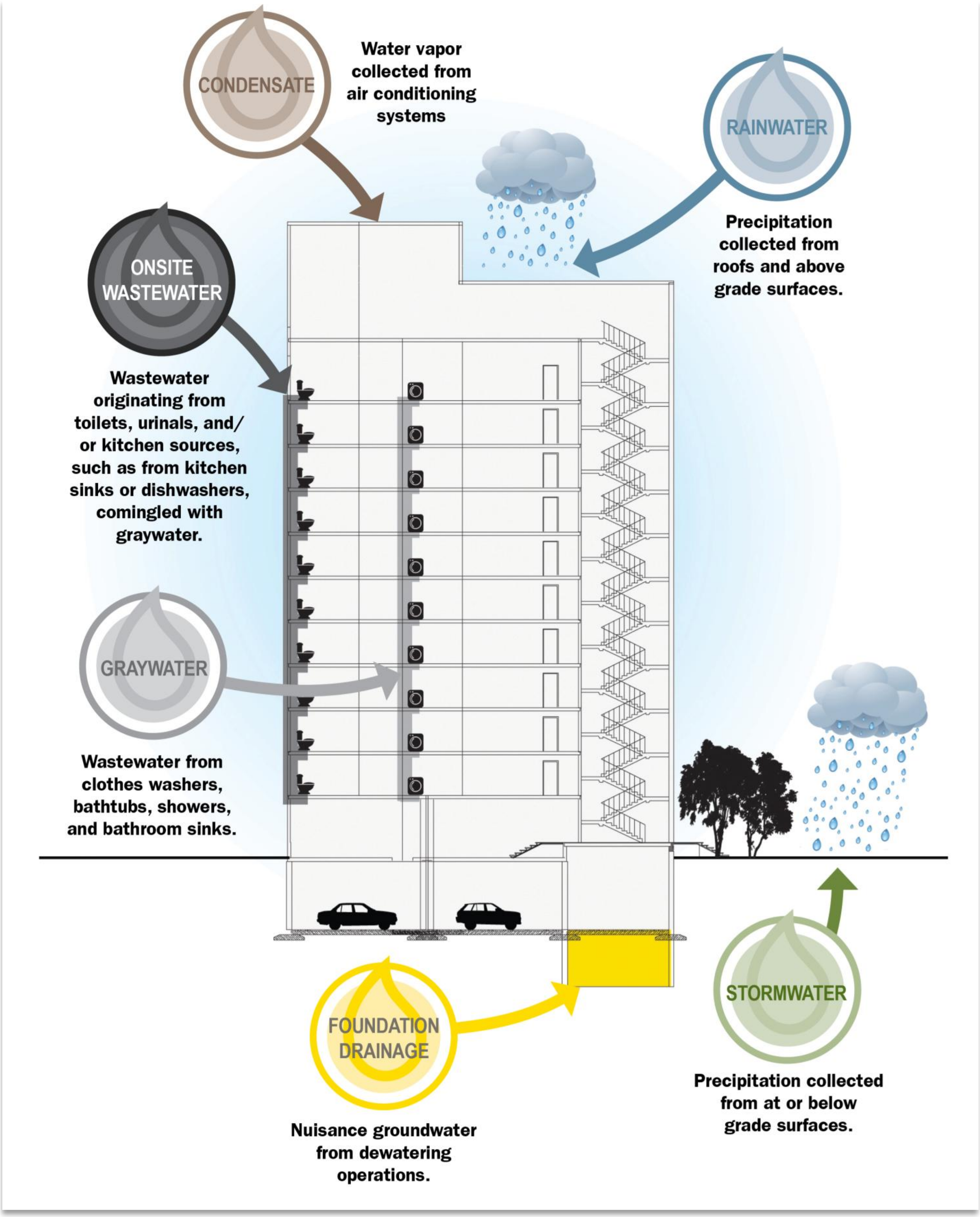


FIGURE 1.2: *Potential source waters for onsite reuse* *[San Francisco Onsite Reuse Program Guidebook p2]*

1.3.2 Non-potable end uses

This handbook focuses on alternative water sources that are used for the following non-potable end uses inside and outside of buildings:

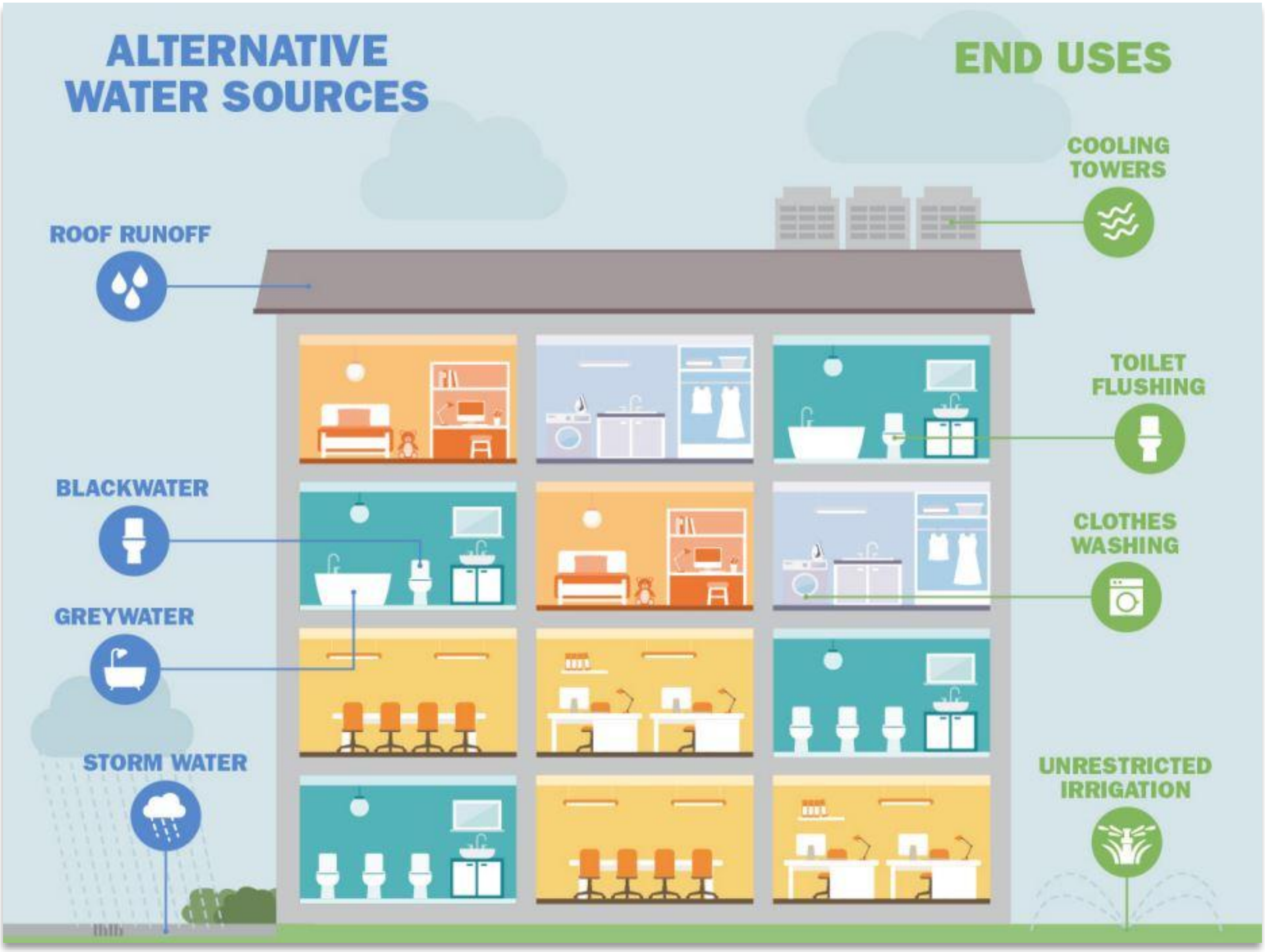


FIGURE 1.3: *Source waters and end uses for ONWS [NBRC ONWS Guidance Manual p2 Figure1]*

Indoors	Outdoors
Toilet and urinal flushing	Irrigation
Drain trap priming	Outdoor water features/fountains and impoundments
Clothes washing (cold water)	Cooling applications
Indoor water features/fountains	Dust control/street cleaning
Process water	

TABLE 1.2: *Non-potable end uses [NBRC ONWS Guidance Manual p2 Figure1]*

1.3.3 Building types

This handbook is focused on the implementation of ONWS at the following implementation scales:

- Multifamily buildings
- Commercial buildings
- Mixed-use buildings
- District-scale projects

The document does not address ONWS implemented in single-family homes or centralized reuse systems such as large, municipal recycled water facilities.

1.4 Unit processes in onsite water reuse

ONWS typically includes five key treatment process groups: flow equalization, pretreatment, biological treatment, filtration, and disinfection.

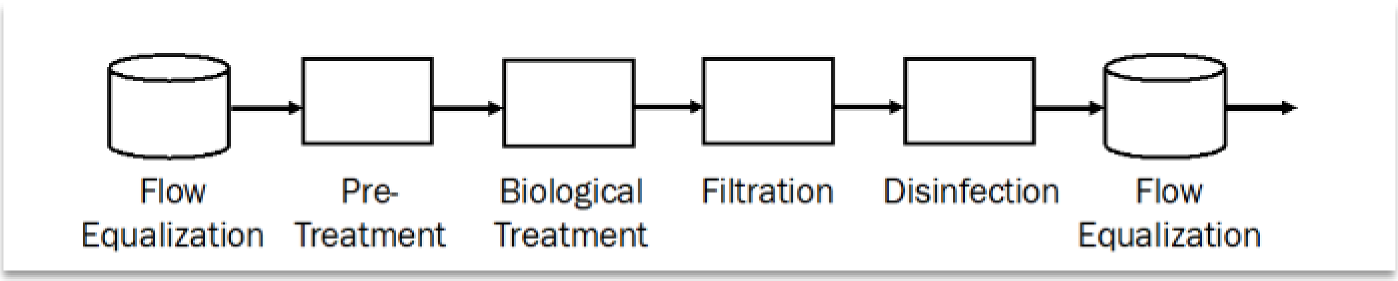


FIGURE 1.4: *The key treatment process groups of the ONWS treatment train [NBRC ONWS Guidance Manual p23 Figure7]*

1.4.1 Flow equalization

Flow equalization is crucial when the supply of source water and demand for non-potable water fluctuate. Therefore, flow equalization is incorporated in the design of ONWS to limit impacts on the sizing and performance of unit treatment processes. [NBRC ONWS Guidance Manual p27]

1.4.2 Pretreatment

The first unit treatment process in many ONWS treatment facilities is pretreatment, with the primary goal of removing coarse materials before downstream treatment processes. If not removed, these coarse materials could potentially damage or plug downstream equipment and reduce the effectiveness of the treatment. [NBRC ONWS Guidance Manual p30]

1.4.3 Biological treatment

Biological treatment is an essential step and the workhorse of ONWS for treating blackwater and graywater. Biological treatment encompasses a range of technologies, including membrane bioreactors (MBRs), conventional activated sludge, and natural systems, such as engineered treatment wetlands. [NBRC ONWS Guidance Manual p31]

1.4.4 Filtration

Filtration clears suspended and colloidal particulate matter by a physical process. Typical treatment technologies include membrane filters (i.e., microfiltration and ultrafiltration), cartridge filters, and reverse osmosis. [NBRC ONWS Guidance Manual p37]

1.4.5 Disinfection

Disinfection refers to the destruction and/or inactivation of pathogenic microorganisms by exposure to a chemical agent or physical process. 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. [NBRC ONWS Guidance Manual p42]

DGS Natural Resources Building in Sacramento, CA that is recycling its graywater onsite *[Photo credit: HTEC]*

Test Your Knowledge

Section 1: Introduction to Onsite Non-potable Water Treatment

1. True or False. The health risk-based framework relies on end-point coliform monitoring to determine whether water is suitable for reuse.

   A. True

   B. False

2. What is the multiple barrier concept?

   A. Maintaining a disinfectant residual to protect against opportunistic pathogens

   B. Use of multiple treatment processes to help provide safe water for reuse and increase reliability

   C. Use of multiple types of alternate water sources in an ONWS

   D. A physical process to clear suspended solids from water

3. What is the primary purpose of pretreatment in an ONWS treatment train?

   A. Remove coarse materials/solids prior to downstream treatment processes

   B. Equalize the supply of source water and demand for non-potable water

   C. Disinfect the water for reuse

   D. Store the water for reuse

4. Which building type is not a focus of the handbook?

   A. Commercial

   B. Mixed use

   C. Residential

   D. Multifamily

5. Which unit process is considered the essential workhorse for treating blackwater and graywater?

   A. Flow equalization

   B. Filtration

   C. Biological treatment

   D. Pretreatment

Membrane tank as part of an ONWS [Photo credit: Aquacell]

Section 2
Roles and Responsibilities

People in many different roles support an ONWS. In a new project, it is essential to identify the operator of the ONWS early in the process and to plan for multiple training sessions between the product manufacturer/system commissioner and the ONWS operator. All staff will require proper training on safe operations, water treatment, and regulatory compliance. [Onsite Water Reuse Lessons Learned p13 para1 bullets; SME input]

Concerning ONWS operators, many of the skills required will align with those used by water, wastewater, or building water system operators. However, some skill-specific knowledge will be needed to address onsite non-potable water reuse. [Onsite Water Reuse Lessons Learned p13 para1 bullets]

In an ONWS, specific roles need to be understood and will be explored in this section:

We will conclude this section by discussing the responsibilities related to operating an ONWS.

2.1 Roles

Multiple roles must be filled to implement a successful ONWS. While we will review some of the roles, this handbook focuses on the operator. Consult local jurisdictions for proper titles and roles.

2.1.1 Operator

- Reads and understands the operations and maintenance manual
- Operates and maintains the ONWS to ensure that treatment goals are met
- Maintains communication between stakeholders (e.g., system owners and building occupants) [Guidebook for Commissioning an Onsite-Water Treatment System in San Francisco p7 para1-4]
- Maintains communication with regulators about system status
- Ensures proper operation, sampling requirements, record keeping and reporting, maintenance, and equipment replacement of the ONWS [NBRC ONWS Guidance Manual p13 bullets]

- Follows permit requirements for operations, maintenance, and reporting. Ensures that the owner is informed as to the status and needs of the system for permit compliance [SME input]
- Follows standard operating procedures (QA/QC)
- Maintains daily responsibilities, including but not limited to:
    - Inspections
    - Routine maintenance
    - Process checks [2024 WPI Onsite Non-potable ECO 2022 Exam Specifications Outline]
- Interfaces with equipment manufacturers on maintenance issues and replacement parts [SME input]

2.1.2 Design engineer

- Is responsible for designing an ONWS that meets the treatment and monitoring requirements of the project and can comply with all permit requirements [NBRC ONWS Guidance Manual p13 bullets]
- Verifies that system performance meets design criteria and treatment requirements
- Assists with design modifications and documents any changes in appropriate reports [Guidebook for Commissioning an Onsite-Water Treatment System in San Francisco p7 para1-4]
- Writes the operations and maintenance plans for operating the system as designed

2.1.3 Regulator

- Reviews and approves design plans for proposed ONWS for compliance with public health requirementsPermits and inspects systems
- Approves operations and maintenance plans
- Reviews compliance reports to ensure proper operations [NBRC ONWS Guidance Manual p13 bullets]

2.1.4 System owner

- Is responsible for permit compliance and ensures that the team is aware of enforcement actions and requirements
- Is responsible for assembling the ONWS team and ensuring that the organizational chart with responsibilities, job descriptions, and contact information is in the operations plan and kept current
- Determines who keeps the operations plans up-to-date, and the validation frequency for ensuring it is up-to-date [SME input]
- Is often the owner of the building that houses the ONWS and the ONWS itself
- May have varying degrees of responsibility in the implementation and permitting of the project
- Hires and manages staff [ONWS System Guidance Manual p13 bullets; SME input]

NOTE: Depending on how the ONWS project is implemented, there may be overlap between the roles.

2.2 Responsibilities

2.2.1 Daily responsibilities

Operators are responsible for the daily operation, monitoring, and maintenance of the ONWS to ensure continuous achievement of treatment goals and to communicate with regulators. Proper operation, reporting, maintenance, equipment replacement, and a clear communication strategy for all operations and maintenance issues will help operators ensure the long-term success of the ONWS. [NBRC ONWS Guidance Manual p4, SME input]

- In addition, the operator's skill set should include the ability to:
- Understand the plumbing of the system and its functionality
- Use a multimeter to troubleshoot fundamental problems (e.g., pump not energizing, blown fuse, relay not closing)
- Measure the water parameters referenced in this document and understand what causes them to be out of spec [SME (IAMPO) input]

2.2.2 Monitoring and reporting responsibilities

Operators must complete compliance reporting, as this is a regulatory requirement to confirm that an ONWS meets the conditions of its operating permit. The specific reporting requirements will vary depending on the permit and jurisdiction. A sampling plan should be developed by the operations and maintenance staff that defines the frequency, location, type of sample, analytical methods, contact information for the lab conducting the analyses, and any other necessary information (e.g., holding times, turnaround times). Data that may be required for compliance reporting may include:

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

An ONWS must be monitored frequently to ensure it performs as designed. Typically, it is most effective to continuously monitor select water quality parameters that serve as surrogates for pathogen LRTs. This monitoring would be conducted using accessible and reliable online instrumentation, correlated with system performance, to achieve the desired treatment goals. Some key monitoring and reporting details that an ONWS operator might need to be familiar with include:

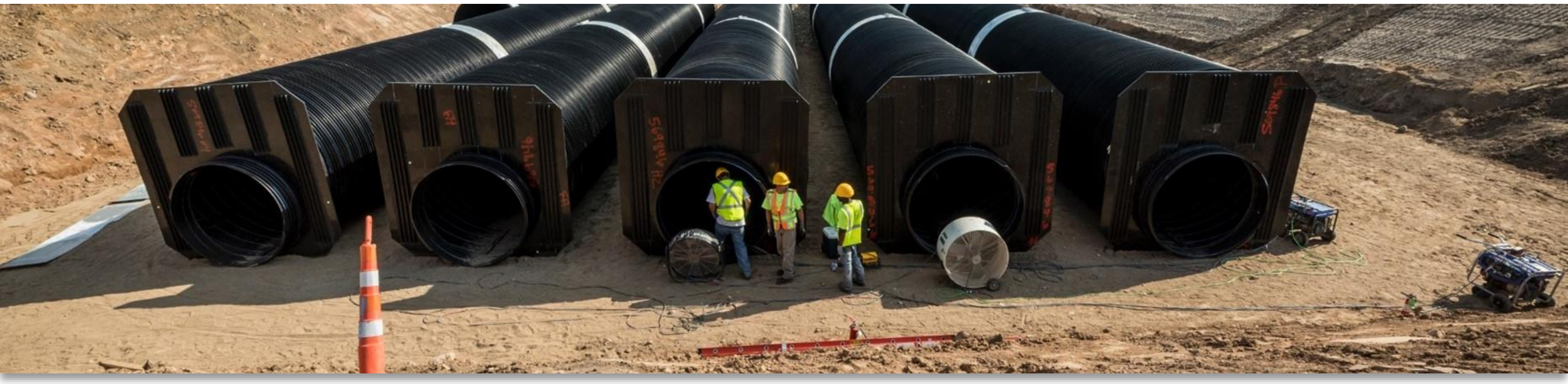
- Monitoring: The operator utilizes continuous monitoring systems to monitor water quality and unit process performance in real-time.
- Control and automation: The operator is responsible for system operations, including shutdown and start-up, based on a specific set of monitoring conditions.
- Alarms: Operators respond to automated alarms triggered by critical malfunction conditions, based on the degree of response required.
- Continuous process verification: Operators perform ongoing confirmation of system performance by monitoring sensors to continuously observe specific parameters, including surrogate parameters correlated with pathogen LRT requirements.
- Data: Operators log and retain data for a prescribed period and share it with necessary team members; telemetry systems are often used for real-time web-based data monitoring.
- Reporting: Operators provide reports to the regulator as required by the permit. [WE&RF Final Report p7 Table1-2, SME input]

City of Austin Permitting and Development Center [Photo credit: Austin Water]

Test Your Knowledge

Section 2: Roles and Responsibilities

1. Which of the following are typical responsibilities of an operator of an ONWS? Select all that apply.
   A. Operates and maintains the ONWS to ensure that all treatment goals are met
   B. Issues permits, reviews, and reviews design plans for the ONWS
   C. Is responsible for designing the ONWS
   D. Maintains communication between stakeholders
2. True or False. The ONWS operator should develop a sampling plan that defines the frequency, location, type of sample, analytical methods, contact information for the lab conducting the analyses, and any other necessary information (e.g., holding times, turnaround times).
   A. True
   B. False
3. Under what conditions are automated ONWS alarms set to notify the operator?
   A. Lunch time
   B. Response to critical malfunction
   C. Update to the organizational chart for the ONWS team
   D. When a toilet is flushed using non-potable water
4. What is the system owner responsible for? Select all that apply.
   A. Writing the operations and maintenance plan for operating the ONWS
   B. Confirming permit compliance
   C. Assembling the ONWS team
   D. Hiring and managing staff
5. The Regulator does not perform which of the following functions?
   A. Reviews plans
   B. Permits systems
   C. Performs routine maintenance
   D. Reviews the compliance report



Installation of underground rainwater storage tank outside of stadium in the City of St. Paul [Photo credit: City of St. Paul]

Section 3
Applicable Regulations/Codes

In section 3, we will cover applicable regulations and codes related to ONWS. We will begin with an overview and then proceed to permit compliance.

3.1 Overview

There are local, state, and/or federal/national regulations and/or codes that must be adhered to when operating an ONWS. This manual does not include an exhaustive list of applicable regulations/codes because they are context-specific; however, some of the national codes that may need to be addressed include:

- 2024 Uniform Plumbing Code, Chapter 15, Chapter 16, Chapter 17, Appendix L, and Appendix S
- 2023 Water Efficiency and Sanitation Standard (WE-Stand)
- 2021 ICC International Plumbing Code

3.2 Permit compliance

A well-designed permitting process for ONWS provides regulators with several opportunities to review and evaluate projects, as well as confirm compliance with the project team (e.g., system owners, design engineers, operators). Different steps must be implemented for ONWS, depending on the project's location. An example of the possible steps and interactions between the project team and regulators is presented in Table 3.1. [NBRC ONWS Guidance Manual p83 para2]

Project Stages	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
Ongoing Monitoring, Reporting, Inspection, and Enforcement	Ongoing monitoring and reporting	– Performance and water quality data review – Inspections and enforcement – Periodic permit renewal

TABLE 3.1: *Example Steps of the Regulatory and Permitting Process for an ONWS. Steps may vary by jurisdiction [NBRC ONWS Guidance Manual p84]*

Let's look at a few of these stages that the ONWS operator is responsible for in a little more detail.

3.2.1 Operations plan

The operations plan is the document with written details on the current operation, maintenance, and management of how to operate the system. The operations plan should be written in a way that allows operators to use it to run the system and understand the communication pathways for all stakeholders. Operations plans should also include an organizational chart that shows positions and job descriptions. The organizational chart should clearly outline the delegation of responsibility, authority, and reporting structure. An operations plan contributes to a system's reliability, emergency preparation, and ability to train new staff, and it reduces costs by outlining the plans for repairs and replacements. [SME input] Before finalizing the design of the ONWS, the operator can provide feedback on the operations plan. The operations plan offers additional details on the specifics of the operation, including monitoring, maintenance, and reporting for the ONWS. The operations plan is often developed after the engineering report and is a critical document that supports discussions between regulators and operators.

While there is often overlap between the engineering report and the operations plan, the operations plan should be a stand-alone document that is referenced, as the operators and operations team may not be involved in the development of the engineering report. [NBRC ONWS Guidance Manual p89 para1-2]

The operations plan is a holistic plan for the whole ONWS. It defines acceptable ranges of operation and performance, including what constitutes a violation of the permit. The operations plan is critical in guiding performance reporting and enforcement, as it defines the level of performance required for ONWS compliance. [NBRC ONWS Guidance Manual p89 para3] An ONWS with a thorough, organized, and updated operations plan that everyone references has better operations, prevention of expensive issues, and clarity between all parties. [SME input]

This document may also describe the start-up and commissioning plan for the ONWS. Finally, the operations plan will include the operations and maintenance manuals for the various unit processes, meters, pumps, and other equipment present on the site. [NBRC ONWS Guidance Manual p89 para2-3] Operators should know where to find the operations plan, how to use it, and how to keep it updated. [SME input]

3.2.2 Permit to operate

The operator is responsible for compliance with the ONWS Permit to Operate. This permit allows the ONWS to produce water for use in the start-up and commissioning of the system. Still, it does not necessarily provide immediate authorization for the distribution and use of the water. The Permit to Operate should be authorized after the regulators have reviewed and approved the following:

- 100% design of the ONWS, including design drawings and specifications
- Final engineering report
- Operations and maintenance plan, including the start-up and commissioning plan
- Construction of the ONWS
- Cross-connection testing

Note that the Permit to Operate may come from either the State or Local level, or both, depending on the system and jurisdiction. [NBRC ONWS Guidance Manual p90 footnote]

3.2.3 Project start-up and commissioning

***FIGURE 3.1:** Operator performing start-up testing [Photo credit: San Francisco Public Utilities Commission]*

3.2.3.1 Project start-up and installation inspection

After the ONWS has been installed, the operator can begin project start-up. Project start-up happens when the ONWS equipment is brought online for the first time to confirm proper installation, calibration, and function. Note that start-up and commissioning are two different tasks. Commissioning refers to the period after project start-up, when the fully functioning system is tested to verify that all equipment and processes meet the design specifications. You can find more information about commissioning in Section 3.2.3.2 and Section 16.

3.2.3.2 Commissioning

After project start-up and during commissioning, the regulators may inspect the ONWS to confirm that it has been constructed and installed in line with the design documents. They may verify the following:

- Installation of proper monitoring at the specific locations
- Use of specified chemicals
- Installation of the correct unit process equipment in the order specified in the design
- Presence of flow diversions
- Provision of backup wastewater disposal and supply options, as needed [NBRC ONWS Guidance Manual p90 para5-6+bullets]

Once the ONWS installation has been inspected and approved, commissioning can begin. Testing of the system will continue during this stage, verifying the proper functioning of critical system elements (e.g., activation of alarms, diversions, and shutdowns), while also demonstrating the system's ability to meet its design performance continuously over a given period. It is also during this time that the operating team will work to optimize their control strategies and perform any necessary challenge tests or tracer studies to verify process performance or design assumptions. [NBRC ONWS Guidance Manual p91 para1]

3.2.4 Ongoing monitoring, reporting, and enforcement

The operator is responsible for ongoing ONWS monitoring and reporting. These requirements should be specified in the operations and maintenance plan, including:

- Parameters to measure
- Frequency and methods for collecting data
- How the data will be analyzed and reported

Updates to the operations and maintenance plan should occur after any significant modification to the operations or design of the ONWS. The process for updating the PO should be outlined in the operations and maintenance plan. The proper functioning of an ONWS can be verified through different mechanisms, including:

- Reviews of periodic performance
- Reviews of water quality monitoring reports
- Routine inspections

The operator should also be aware of and respond to any enforcement actions that may occur due to violations. It will be necessary to be mindful of the types of violations and the associated penalties. [NBRC ONWS Guidance Manual p91 para4-5]

WaterHub's greenhouse, administrative building, and reclaimed water storage tank at Philip Morris USA in Richmond, VA [Photo credit: Sustainable Water]

Test Your Knowledge

Section 3: Applicable Regulations/Codes

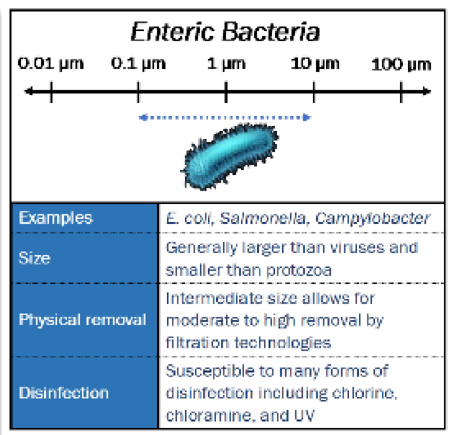
1. What is an operations plan?
   A. A document with written details on the current operation, maintenance, and management procedures for operating the ONWS
   B. A permit that provides authorization for the distribution and use of the non-potable water
   C. A document that is used to record all water quality sampling results
   D. A document that is used to obtain a building permit from the local jurisdiction
2. When does commissioning occur?
   A. During the design of the ONWS
   B. During the system construction inspection with the local jurisdiction
   C. Before the cross-connection test
   D. After the project start-up, when the fully functioning ONWS is tested
3. During commissioning, a regulator may inspect the ONWS to confirm it was installed in accordance with the design documents. They may verify the following: (Select all that apply.)
   A. Installation of the correct treatment process equipment
   B. Use of specific chemicals
   C. The use of drinking water fountains onsite
   D. The percent occupancy of the building
4. True or False. The operator should ignore any enforcement actions if a permit violation occurs.
   A. True
   B. False
5. Which stage is not typically found during project start-up?
   A. Confirm proper installation
   B. Confirm proper calibration
   C. Confirm water savings
   D. Confirm system function

Onsite reuse system's mechanical room at Philip Morris USA in Richmond, VA *[Photo credit: Sustainable Water]*

Section 4
Risk-based Log Reduction Targets and Pathogen Crediting

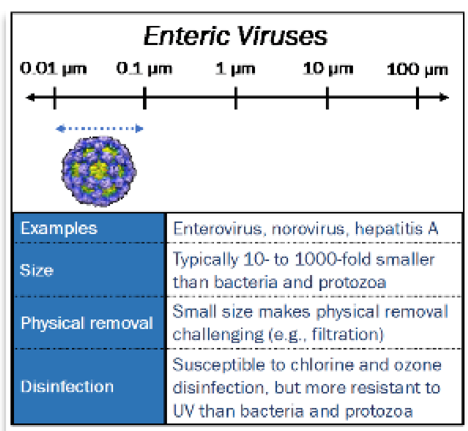
4.1 General Microbiology Overview

For ONWS, enteric pathogenic microorganisms — those that cause gastrointestinal illnesses — are the most significant public health issue to address in a non-potable application. Enteric pathogens include commonly known organisms like bacteria (e.g., salmonella, pathogenic E. coli), viruses (e.g., enterovirus, norovirus), and protozoa (e.g., *Giardiam Cryptosporidium*). The control of pathogens is critical for ONWS because pathogens 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. [NBRC ONWS Guidance Manual p15-16]



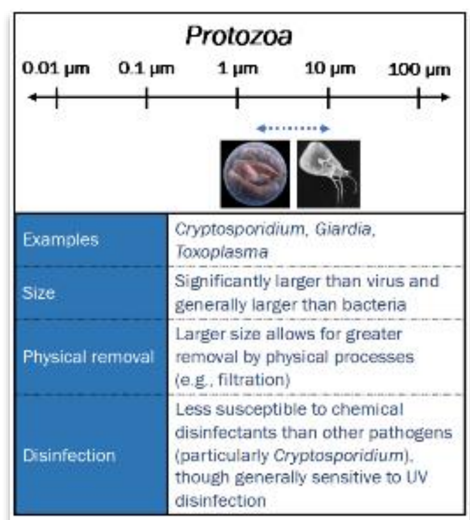
Examples	*E. coli, Salmonella, Campylobacter*
Size	Generally larger than viruses and smaller than protozoa
Physical removal	Intermediate size allows for moderate to high removal by filtration technologies
Disinfection	Susceptible to many forms of disinfection including chlorine, chloramine, and UV

FIGURE 4.1: *Enteric bacteria [NBRC ONWS Guidance Manual p16 Graphic]*



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

FIGURE 4.2: *Enteric viruses [NBRC ONWS Guidance Manual p17 Graphic]*



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

FIGURE 4.3: *Protozoa [NBRC ONWS Guidance Manual p18 Graphic]*

4.2 Risk-based Health Goals

4.2.1 Log reduction concept

The risk-based framework identifies a health benchmark, such as an acceptable level of infections in a population. It uses that benchmark to calculate the level of treatment needed to achieve the goal. Developed using Quantitative Microbial Risk Assessment (QMRA), risk-based LRTs are set for the treatment of pathogens, including viruses, protozoa, and bacteria. The infection-based benchmark (on which the NBRC's 2017 recommendations were based) seeks to limit the number of infections in the exposed population to levels that are so low that they can be considered negligible.

By preventing infections, it reduces the risk of illness for all populations, including sensitive populations who may have worse outcomes from an illness. The 1 in 10,000 annual risk of infection has been used as a de facto or explicit benchmark for several state-level regulations.

Since 2017, LRTs using the infection-based benchmark have been adopted by states such as Colorado and cities such as San Francisco in their respective regulations for ONWS.

In 2025, the US EPA produced a report summarizing new LRTs based on the same modeling framework and QMRA process. The Risk-Based Framework for Developing Microbial Treatment Targets for Water Reuse report concluded that the most prominent frameworks in the field of water reuse have utilized two benchmarks based on limiting either infections or disability adjusted life years (DALYs). The infection-based benchmark and DALY health benchmark are both considered to be protective of public health yet manage for different public health endpoints.

The NBRC has reviewed and considered the 2025 EPA report. As a result, the NBRC has updated its 2017 guidance for OWS used in commercial, multifamily, and mixed-use buildings for landscape irrigation and indoor non-potable use as shown in Table 4.1. The NBRC respects local context, and both infection-based and DALY frameworks can be used by policy makers and organizations to implement scientifically defensible microbial treatment targets for a broad range of water reuse applications. [SME input]

End Use	Source Water	Virus	Protozoa	Enteric Bacteria
Indoor non-potable use	Onsite wastewater	10.0	6.5	5.5
	Graywater	7.5	4.0	3.5
	Stormwater (10% wastewater)	8.0	6.0	5.5
	Roof runoff	n/a	1.0	3.5
Unrestricted irrigation	Onsite wastewater	8.5	6.5	5.5
	Graywater	6.5	4.0	3.0
	Stormwater (10% wastewater)	7.5	5.0	4.5
	Roof runoff	n/a	0.5	3.5

Table 4.1: *NBRC's 2025 Recommended LRTs for ONWS [Adapted from USEPA Risk-Based Framework]*

The recommended standard for pathogen removal and/or inactivation is to require a treatment train in which unit processes are collectively credited to meet selected LRTs. During operation, the performance of each treatment process is continuously monitored using microbial, chemical, or physical indicator(s) or surrogate parameter(s) that verify their ability to achieve the credited pathogen removal and/or inactivation. Along with treatment processes needed for sufficient log reduction credits, other treatment goals include the reduction of organics, particulates, and nutrients and the need to deliver aesthetically acceptable water. [NBRC Health Risk-based Benchmarks p5,7]

LRTs may vary depending on local context, so it's important for operators to understand the local regulations and permit compliance requirements.

4.3 Influent characteristics of alternate water sources

Both the type of building and the type of source water(s) determine the quality, quantity, and time 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 is important because it 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 midmorning or midafternoon. In contrast, similar spikes may occur in a residential building during morning (before work hours) and evening (after work hours) when the building is occupied.

4.3.1 Rainwater

- Quality: Generally of higher purity compared to other non-potable water sources, but it can contain various impurities washed off roof surfaces
- Turbidity: Relatively low, though it can increase during the initial runoff, commonly referred to as the "first flush," which contains most of the accumulated debris
- Contaminants: Besides dust and debris, they can include heavy metals from roofing materials, as well as bacteria and microbial pollutants

4.3.2 Stormwater

- Quality: Highly variable; influenced by land use, rainfall intensity, and surface conditions; generally lower quality than treated water
- Turbidity: High due to suspended solids, such as silt, organic matter, and debris; typically ranges from 10 to >1,000 NTU
- Contaminants: Includes BOD (5–30 mg/L), TSS (20–500+ mg/L), total coliforms (10^3–10^6 CFU/100 mL), nutrients (N, P), hydrocarbons, heavy metals, and pathogens from fecal sources

FIGURE 4.4: *Stormwater management can help reduce urban flooding [Photo credit: San Francisco Public Utilities Commission. Not published in public document. Permission to use.]*

4.3.3 Graywater

- Quality: Variables are based on household products and activities; may contain soap, detergents, hair, body oils, food particles, and minor pathogens
- Turbidity: Moderate, higher than rainwater due to organic and inorganic materials suspended in it, but typically lower than blackwater
- Contaminants: Surfactants from soaps and detergents, suspended solids, organic matter, nutrients such as nitrogen and phosphorus, and mild to moderate levels of pathogens

4.3.4 Blackwater

- Quality: Contains a high concentration of organic matter, pathogens, and nutrients, making it the most contaminated of the water types considered here
- Turbidity: Very high due to fecal matter and other solids present
- Contaminants: Significant levels of BOD and chemical oxygen demand (COD), ammonia, nitrates, pathogens (bacteria, viruses, and protozoa), and potentially harmful chemicals and pharmaceuticals

Table 4.2 provides typical ranges of water quality values that may be encountered for different types of source waters. This information can serve as a general guide for what to expect from different source waters; however, there is no substitute for site-specific characterization of the ONWS source waters. [NBRC ONWS Guidance Manual p27-28]

Type of Source Water	Total Coliform (CFU/100ml)*	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 - 1000	300 – 600	No data	6 – 9	50 - 150

TABLE 4.2: *Typical ranges of source water quality for various sources*

**CFU/100ml is colony-forming units per 100 milliliters*

[NBRC ONWS Guidance Manual p28 Table5]

Onsite water reuse system operators [Photo credit: San Francisco Public Utilities Commission]

Test Your Knowledge

Section 4: Risk-based Log Reduction Targets and Pathogen Crediting

1. What are the enteric pathogens of most significant concern in ONWS? (Select all that apply.)
    - A. Fungi
    - B. Bacteria
    - C. Protozoa
    - D. Viruses
2. What is the risk-based framework?
    - A. A list of allowable non-potable end uses
    - B. Identifies a health benchmark, such as an acceptable level of infections in a population and uses that benchmark to calculate a level of treatment needed to achieve the goal
    - C. Use of multiple treatment processes to help provide safe water for reuse and increase reliability
    - D. The destruction or inactivation of pathogenic microorganisms by exposure to a chemical agent or physical process
3. How is the quality of rainwater generally described?
    - A. Highly variable; influenced by land use, rainfall intensity, and surface conditions; generally lower quality than treated water
    - B. Contains a high concentration of organic matter, pathogens, and nutrients, making it the most contaminated of the alternate water sources
    - C. Generally of higher purity compared to other alternate water sources but can contain various impurities washed off roof surfaces
    - D. Variables are based on household products and activities; may contain soap, detergents, hair, body oils, food particles, and minor pathogens
4. LRT is an acronym for which of the following phrases?
    - A. Log Reduction Target
    - B. Long Reach Chain
    - C. Log Reaction Time
    - D. Long Range Target
5. The de facto benchmark for annual risk of infection used to create Log Reduction Targets is which of the following?
    - A. 1 in 10 annual risk of infection
    - B. 1 in 5,000 annual risk of infection
    - C. 1 in 10,000 annual risk of infection
    - D. 1 in 100,000 annual risk of infection

Emory University Water Hub *[Photo credit: Sustainable Water]*

Section 5
Flow Equalization and Pretreatment

Typically, one of the first steps in a treatment train in an ONWS is flow equalization, which helps balance the extreme fluctuations in both flow and quality that are challenging for the unit's treatment processes. Flow equalization is followed by pretreatment, which aims to remove coarse materials before downstream treatment processes. If this material is not removed, damage could occur, or downstream equipment could become clogged, ultimately decreasing the effectiveness of the treatment.

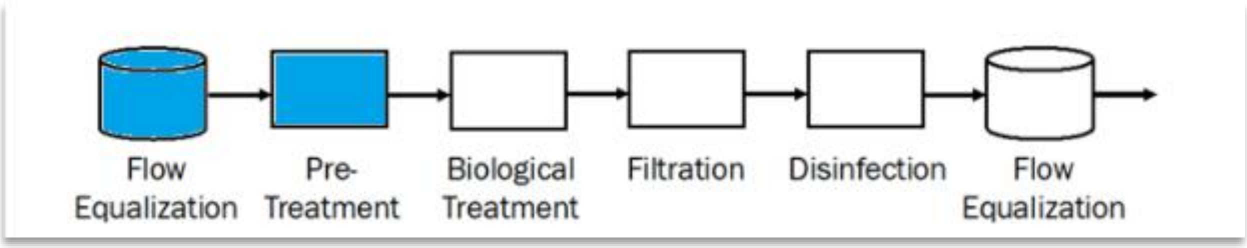


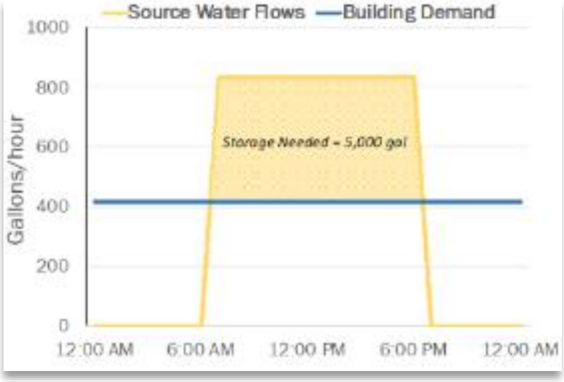
***FIGURE 5.1:** Treatment train and flow equalization* *[NBRC ONWS Guidance Manual p27 Figure9]*

5.1 Flow equalization

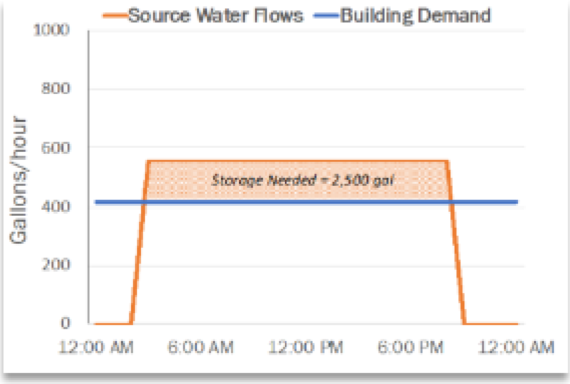
The purpose of flow equalization is to help balance variable fluctuations in both flow and quality that are challenging for the unit treatment processes. Most unit treatment processes have an optimal operating range – defined by minimum and maximum values – where they consistently meet the system's design and performance requirements and remain online. This optimal range occurs when the system operates under consistent conditions, requiring minimal adjustments over time. [NBRC ONWS Guidance Manual p28 para1]

Example of flow equalization

There are two buildings, each with a total of 10,000 gallons of source water collected over the course of a day, and the building demand is evenly distributed throughout the day. In Building A, source water is generated for 12 hours per day (between 6 a.m. and 6 p.m.) and requires 5,000 gallons of storage to meet the continuous building demands when source water is not being generated. In Building B, source water is generated for 18 hours per day (between 2 a.m. and 8 p.m.) and requires a storage capacity of 2,500 gallons.



***GRAPH 5.1**: Building A*



***GRAPH 5.2**: Building B*

This example illustrates that when source water is generated over a shorter period, a larger storage volume is required to meet a constant demand. [NBRC ONWS Guidance Manual p29 Figure10]

As the example shows, the storage volume equalizes the variable influent flow to ensure that demands can be met. If an ONWS experiences variability in both influent flow and treated water demand, flow equalization may be needed at both the beginning and the end of a treatment train. [NBRC ONWS Guidance Manual p28 para2]

Accurately calculating the volume of a tank is crucial for onsite water reuse operators. This knowledge ensures the system can store and manage the appropriate amount of water for reuse, which is essential for:

- **Cost-efficiency:** Avoiding over- or under-sizing tanks.
- **Environmental compliance:** Preventing overflow and contamination.
- **System optimization:** Supporting treatment processes and peak usage planning.
- **Emergency preparedness:** Ensuring adequate reserves during shortages.

In the field, an operator may encounter a situation where they need to determine how many gallons of storage remain in the tank based on a fill line marked on the tank. [SME input]

Example Calculations:

<u>Formula:</u>

Rectangular Tanks

Volume (gallons) = Length × Width × Water Depth × 7.48 (gallons/ft^3)

Cylindrical Tanks

Volume (gallons) = $\pi \times r^2$ × Water Depth × 7.48 (gallons/ft^3)

Question:

An onsite water reuse operator is preparing for a major irrigation project and needs to calculate how much water can be stored using two large tanks:

- **Tank A** is a rectangular tank that measures **40 feet in length, 25 feet in width**, and is filled with water to a depth of **15 feet**.
- **Tank B** is a **cylindrical tank** with a **radius of 15 feet** and is filled with water to a depth of **20 feet.**

Question:

How many gallons of water are stored in each tank? What is the **total volume of water** available from both tanks combined?

Answer:

Tank A (Rectangular)

Volume = 40 × 25 × 15 × 7.48 = 112,200 gallons

Tank B (Cylindrical)

Volume= $\pi \times (15)^2 \times 20 \times 7.48 \approx 105{,}746$ gallons

Total Water Volume

112,200 + 105,746 ≈ 217,946 gallons

5.2 Pretreatment

5.2.1 Screening

Screening is a pretreatment tool that involves a screen with openings of uniform size used to retain solids. There are two main types:

- Coarse: used to handle larger solids and debris, separate them from the process flow, and collect them later for removal
- Fine: used to remove smaller solids and debris, but can become easily clogged

Both types can be designed to self-clean, allowing the process to run autonomously and decreasing potential maintenance issues. The residual waste can be discharged directly into the sewer, reducing the need for handling and off-site disposal. Self-cleaning screens are a good choice for an ONWS system. [NBRC ONWS Guidance Manual p30 para2]

The pretreatment tool for stormwater and harvested rainwater may be a vortex filter. These work by creating hydraulic conditions to separate solids, and possibly hydrocarbons, from the main process water and collecting the waste for later disposal. The removal of solids is done manually and must be maintained regularly by cleaning the filter element. [NBRC ONWS Guidance Manual p30 para3]

As an onsite water reuse operator, maintaining the rainwater vortex filter is a key responsibility. This involves turning off the water supply, opening the filter housing, and removing the filter insert. You then clean the insert thoroughly with a hose or brush to remove accumulated debris. After inspecting and cleaning the filter housing, you reassemble the filter and turn the water supply back on, checking for leaks to ensure proper function.

Referring to the manufacturer's Standard Operating Procedures (SOP) is crucial. These guidelines provide specific instructions for your filter model, ensuring safe and effective maintenance. This routine task underscores the importance of paying attention to detail and adhering to established procedures in your role. [NBRC ONWS Guidance Manual p30 para3]

Process	Pros	Cons
Coarse screen	Removes large solids and debris Robust removal of solids and debris	Does not remove finer solids and allows them to continue downstream
Fine screen	Improves water quality through decreased TSS and turbidity	May not be able to handle larger solids/debris, potentially increasing maintenance needs
Vortex filter	Removes large solids, debris, and hydrocarbons	Typically requires manual filter cleaning

TABLE 5.1: *Summary of pretreatment screening [NBRC ONWS Guidance Manual p31 Table7]*

5.2.1.1 First flush diverters

First flush diverters are used in rainwater and stormwater systems. They are devices operated by mechanical float valves or other types of automatic control that divert a quantity of rainwater or stormwater collected from a surface following the onset of a rain event to help reduce the load of dust and dirt that comes with the first flush. [SFDPH Directors Rules and Regulations p5 para8; SME (TR) input]

First flush diverters must be cleaned out regularly to serve their purpose, and in fact, should be emptied before every storm event to prevent mixing diverted ("dirty") water with fresh flow. First flush diverters can be designed with a continuous drain to eliminate the need for emptying between rain events. However, it should be considered that excessive "bleeding" can reduce the volume of rainwater available for non-potable use, especially in climates with light rainfall and/or long dry seasons. [Blue Barrel Rainwater Catchment Systems, n/d]

Additionally, many states have adopted code and refer to ARCSA/ASPE 63 and ARCSA/ASPE/ANSI 78-2023 to establish simple standards for building safe and effective rainwater and stormwater systems. In the state of California, one key requirement is that systems must be equipped with a "debris excluder" (e.g., a leaf eater), and in fact all openings must be protected by 16th inch (1500 microns) mesh, including the inlet. This mesh prevents particulates from clogging the system and keeps insects and other small creatures out. [Blue Barrel Rainwater Catchment Systems, n/d]

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5.2.1.2 Settling tanks and grinder pumps

FIGURE 5.2: *Example of a solids separation filter used at the Salesforce Tower in San Francisco, CA where the building is recycling its blackwater [Photo credit: San Francisco Public Utilities Commission]*

Primary treatment in blackwater systems can consist of a settling tank with a grinder pump. In a two-chamber tank, the trash chamber allows coarse solids to settle with the liquid waste overflowing through screens into the settling chamber. The trash chamber has a grinder pump to periodically pump settled solids to the sewer system.

The settling chamber provides additional residence time for additional solids to settle out. An effluent filter at the settling chamber overflow retains floatable waste in the settling tank as well. Accumulated solids in the settling chamber should be pumped out periodically by a licensed septic tank pumping service. Vactor trucks should be scheduled to pump out the settling tank at least every two years, but exact frequency is project specific. [SME input]

Grinder pumps take larger material and grind it into smaller pieces that pass easier through pumps. Grinder pumps require regular preventive maintenance and periodic replacement of the cutter mechanisms. [WWTF 2 Ch7 p93 para2]

Maintaining grinder pumps in an ONWS involves several key tasks to ensure efficient operation and longevity:

- Regular inspections: Check the grinder pump for signs of wear or damage. This should be done periodically to catch any issues early.
- Servicing: Have the grinder pump serviced by an authorized specialist every three to five years, or as recommended by the manufacturer.

- Cleaning: Keep the area around the grinder pump clear of debris and obstructions to prevent clogs and ensure smooth operation.
- Power backup: Ensure there is an alternate power source, like a generator, to keep the pump operational during power outages.

Following these maintenance steps helps prevent major issues, extends the pump's lifespan, and ensures the system runs efficiently. Always refer to the manufacturer's guidelines for specific maintenance procedures and schedules [cummins-wagner.com Grinder Pump Maintenance p2 para4, 7, 8; p9 para1, 7; southflls.com A Guide to Grinder Pump Maintenance p3 para4, 6]

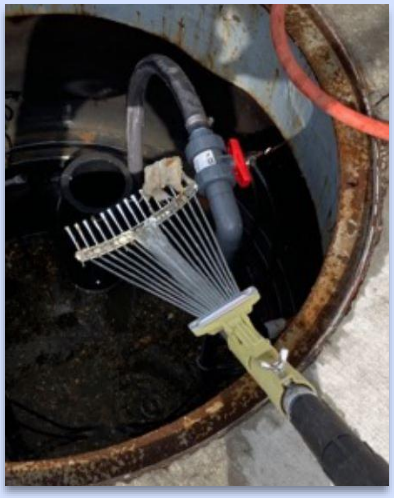

FIGURE 5.3: *Example of cleaning non-flushable items from a wetland treatment system [Photo credit: Denver Water]*

5.2.1.3 Non-flushable items

Operators should be aware that building occupants may flush wipes and other non-flushable items. Operators can work with building management to educate occupants on what specifically can't go down the drain. [SME input, SFPUC Lessons Learned p13]

Denver Water's Onsite Non-potable Water System [Photo credit: Denver Water]

Test Your Knowledge

Section 5: Flow Equalization and Pretreatment

1. What is the purpose of flow equalization in an ONWS treatment train?
   A. Collect the initial runoff from a building's roof
   B. Help balance variable fluctuations in both flow and quality that are challenging for the treatment processes
   C. Process to screen large solids and debris
   D. Monitor the quality of the incoming source water in real time
2. True or False. If an ONWS experiences variability in both influent flow and treated water demand, flow equalization should only be considered at the beginning of the treatment train.
   A. True
   B. False
3. Which is not considered a pretreatment screen?
   A. Course Screen
   B. Vortex Filter
   C. Fine Screen
   D. First flush divertor
4. Which of the following are key tasks to ensure efficient operation of a grinder pump? (Select all that apply.)
   A. Ensuring there is a backup power supply to keep the pump operational during outages
   B. Regular inspections for signs of wear or damage
   C. Keeping the pump clear of debris and obstructions
   D. Having the pump serviced every 3 to 5 years, or as recommended by the manufacturer
5. What can an operator do to prevent non-flushable items from clogging the ONWS?
   A. Work with building management to educate occupants about what shouldn't go down the drain
   B. Encourage occupants to flush wipes down the toilet
   C. Increase the volume of potable make-up water
   D. Purchase a new hose

Chase Center in San Francisco, which is an ONWS [Photo credit: Chase Center]

Section 6
Biological Treatment

6.1 Biological treatment overview

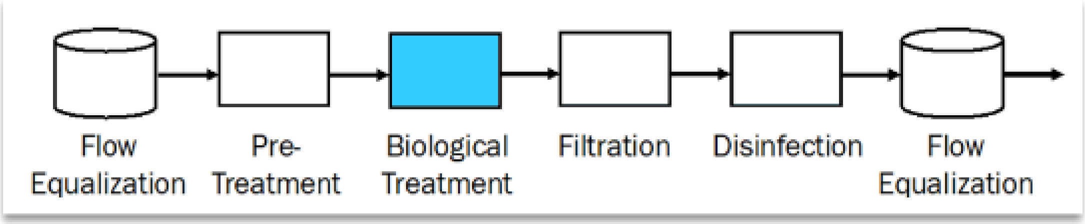

FIGURE 6.1: *Biological treatment in a treatment train* [NBRC ONWS Guidance Manual p36 Figure14]

Biological treatment, also known as *secondary treatment* in an ONWS, is an essential step in the treatment train, particularly when treating blackwater, graywater, and stormwater. Biological treatment steps help remove the following constituents from the source water:

- Biological oxygen demand
- Suspended solids
- Dissolved organic matter
- Nutrients
- Pathogens

Key benefits of using biological treatment include:

- Improving the reliability of pathogen reduction performance in downstream processes such as UV, chlorine, or ozone disinfection.
- Enhancing the operational reliability of downstream processes, such as membrane filtration, reverse osmosis, or UV disinfection, is crucial.
- Minimizing issues with aesthetics (color and odor).
- Minimizing regrowth of microorganisms (including Legionella) in the distribution system. [SFPUC Onsite Water Reuse Program Guidebook p17]

In general, biological treatment for an ONWS utilizes aerobic processes, including suspended growth, attached growth, and hybrid suspended/attached growth. These processes are incorporated into biological treatment technologies, such as membrane bioreactors (MBRs) and conventional activated sludge processes, as well as natural systems (e.g., engineered treatment wetlands). [NBRC ONWS Guidance Manual p31 para2]

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This section is heavily focused on MBR technology commonly used in onsite systems; additional info is provided on activated sludge and engineered wetland systems. There are other kinds of biological treatments, such as engineered wetlands, aerobic treatment, and anaerobic treatment.

6.2 Goals of biological treatment

6.2.1 BOD, TSS, and MLSS

6.2.1.1 Biochemical Oxygen Demand (BOD)

- Impact: High BOD levels indicate a high concentration of organic matter, which can increase the microbial activity in the bioreactor. This can lead to higher oxygen demand and potential overloading of the system.
- Control: Regular monitoring and maintaining optimal BOD levels are crucial to ensure efficient biological treatment and prevent system overload.

6.2.1.2 Total Suspended Solids (TSS)

- Impact: High TSS levels can lead to membrane fouling, reducing the efficiency of the filtration process. TSS includes particles like sand, silt, and organic matter that can clog the membranes.
- Control: Effective pretreatment and regular cleaning of membranes are essential to manage TSS levels and maintain system performance.

6.2.1.3 Mixed Liquor Suspended Solids (MLSS)

- Impact: MLSS represents the concentration of suspended solids in the bioreactor, including microorganisms and non-biodegradable materials. High MLSS levels can increase membrane fouling and viscosity, affecting filterability and system efficiency.
- Control: Maintaining optimal MLSS concentrations (typically 8,000-12,000 mg/L) is crucial for balancing microbial activity and minimizing fouling.

6.2.2 BOD reduction, and solids removal (TSS reduction), and nutrient reduction

The goal is to reduce TSS, turbidity, and BOD by 85%-95% through biological treatment. This is an essential treatment step for blackwater, graywater, and stormwater to prepare the water for downstream treatment and distribution. [NBRC Guidance Manual Training Module4 slides 10-11] Per the EPA's 2012 Guidelines for Water Reuse, it's recommended to achieve BOD $\leq$ 10mg/L and turbidity $\leq$ 2 NTU in the treated water. Other references recommend the BOD and TSS should not exceed an average of 10mg/L to limit the microbial regrowth in the ONWS distribution system. [NBRC ONWS Guidance Manual p32 para2]

6.2.3 Ammonia reduction

Blackwater and graywater may have significant levels of ammonia. Reducing ammonia is important because ammonia impacts the ability to have effective free chlorine disinfection. Nitrification biologically converts ammonia to nitrate. This requires aerobic conditions and appropriate solids retention time. Reducing ammonia will ultimately provide greater reduction in BOD and improve UVT. [NBRC Guidance Manual Training Module4 slide13]

6.2.4 Aesthetics (color and odor)

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. [NBRC ONWS Guidance Manual p39]

6.3 Types of biological treatment

6.3.1 Membrane bioreactors (MBRs)

A membrane bioreactor (MBR) is an advanced wastewater treatment technology that combines biological treatment with membrane filtration. It is widely used in OWRS to produce high-quality effluent suitable for non-potable applications such as irrigation, toilet flushing, and cooling tower makeup.

MBRs combine suspended growth biological treatment with an integrated membrane system to provide enhanced organics and suspended solids removal. This integration is advantageous to the ONWS because it eliminates the need for a separate gravity sedimentation, or clarification, process, which, in turn, reduces the overall footprint. As a result, MBRs tend to be a good fit for smaller sites, which are typical of an ONWS. [NBRC ONWS Guidance Manual p32 para5]

FIGURE 6.2: *Schematic of an MBR [NBRC ONWS Guidance Manual p33 Figure13]*

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, ~0.1 µm pore size) membrane. These systems have several pathogen reduction mechanisms, including:

- Size exclusion
- Adsorption
- Biodegradation

In addition, 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. It should be noted that predation by larger organisms has been shown to reduce the concentrations of some smaller pathogens. [NBRC ONWS Guidance Manual p34 Table8]

An additional benefit of MBRs is that there are existing frameworks that have been accepted for assigning pathogen reduction credits – the Australian WaterVal Validation Protocol and the MBR Validation Protocols for Water Reuse. [Water Research Foundation Project No.4997 p3 Abstract]

Under the Australian WaterVal Protocol, ONWS can receive Tier 1 pathogen credits (1.0 for virus and 2.5 for protozoa) if the MBR is operated within the operating envelope (see Table 6.1 below). [NBRC ONWS Guidance Manual p35]

In comparison, the MBR Validation Protocols for Water Reuse [WRF Project No. 4997] does not require monitoring of all WaterVal Tier 1 parameters; instead, only continuous monitoring of turbidity is required. As long as turbidity is below 0.2 NTU 95% of the time and never above 0.5 NTU, the MBR can be credited with 1/2.5/2.5 log reduction for virus/Giardia/Cryptosporidium, respectively. It should be noted that while this protocol has been accepted by California regulators, ONWS design engineers in other states should consult with their local and state regulators. [SME input]

Parameter	Units	Minimum	Maximum
Bioreactor pH	pH units	6	6
Bioreactor dissolved oxygen	mg/L	16	30
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/m²/h	--	30
Turbidity	NTU	--	0.2

TABLE 6.1: *Summary of MBR Operating Envelope for Tier 1 Default LRV Credits [NBRC ONWS Guidance Manual p35 Table10]*

6.3.1.1 Key considerations for operating and maintaining MBRs

MBRs can take weeks or months to establish a stable population of microorganisms needed to meet treatment standards and complete commissioning, so it is important to build in sufficient time to test the MBR during commissioning. Operators need to know that reduced influent due to low occupancy impacts the operability of MBRs as they need consistent influent to treat water effectively. In addition, they may want to consider separating graywater or blackwater treatment skids with MBRs from rainwater treatment skids so they can be operated independently. [SFPUC Lessons Learned Guidebook p10]

Other key considerations include the following:

- Regular monitoring and maintenance
    - Transmembrane pressure (TMP): Regularly monitor TMP to detect early signs of membrane fouling
    - Flux rates: Keep track of flux rates to ensure optimal performance and adjust operational parameters as needed
    - Cleaning protocols: Implement routine cleaning protocols, including chemical cleaning and backwashing, to maintain membrane permeability
- Solids management

- Mixed liquor suspended solids (MLSS): Maintain appropriate MLSS levels to balance biomass concentration and minimize fouling
    - Sludge handling: Efficiently manage sludge production and disposal to prevent system overload and maintain treatment efficiency
- Air Scouring
    - Frequency and intensity: Optimize the frequency and intensity of air scouring to effectively dislodge foulants without excessive energy use
    - Diffuser maintenance: Regularly inspect and maintain air diffusers to ensure consistent air distribution and prevent clogging
- System calibration and automation
    - Automated controls: Utilize automated control systems to adjust air scouring, backwashing, and chemical dosing based on real-time data
    - Sensor calibration: Regularly calibrate sensors and monitoring equipment to ensure accurate readings and reliable system performance
- Water quality monitoring
    - Effluent quality: Continuously monitor effluent quality to ensure compliance with regulatory standards and identify any treatment issues
    - Nutrient levels: Keep track of nutrient levels (e.g., nitrogen, phosphorus) to optimize biological treatment processes and prevent nutrient imbalances
- Operator training and safety
    - Training programs: Provide comprehensive training for operators on MBR operation, maintenance, and troubleshooting
    - Safety protocols: Implement safety protocols for handling chemicals, managing equipment, and responding to emergencies
- Regulatory compliance
    - Permitting requirements: Ensure compliance with local and state regulations regarding water reuse and discharge standards
    - Record keeping: Maintain detailed records of system performance, maintenance activities, and water quality monitoring for regulatory reporting

By focusing on these key considerations, operators can ensure the efficient and reliable performance of MBRs in OWRS, leading to sustainable and high-quality water reuse operation. [SFPUC Lessons Learned Guidebook p10; SME input]

6.3.1.2 Basic operations

- Biological treatment (also known as activated sludge)
    - Aeration tank: Wastewater enters the aeration tank, where it is mixed with activated sludge containing microorganisms. These microorganisms break down organic matter and nutrients in the wastewater through biological processes.
    - Aeration: Air is supplied to the aeration tank to maintain aerobic conditions, promoting the growth and activity of the microorganisms.
- Membrane filtration
    - Membrane module: The mixed liquor from the aeration tank flows into the membrane module, which contains either hollow fiber or flat sheet membranes.
    - Filtration: The membranes act as a physical barrier, allowing clean water (permeate) to pass through while retaining suspended solids, bacteria, and other contaminants.
    - Permeate collection: The filtered water (permeate) is collected and can be further treated or directly reused for non-potable applications.
- Solids Management
    - Sludge retention: The retained solids, including excess biomass and other particulates, are concentrated in the bioreactor.

    - Sludge removal: Periodically, excess sludge is removed from the system to maintain optimal biomass concentration and prevent overloading.
- Air Scouring
    - Bubble formation: Air is injected into the membrane module to create bubbles that rise through the membranes.
    - Shear forces: The movement of bubbles generates shear forces that help dislodge foulants from the membrane surface, reducing fouling and maintaining permeability.

6.3.1.3 Process control

Wasting rates

Wasting rates are defined as the excess quantity (mg/L) of microorganisms that must be removed from the process to keep the biological system in balance. [Sacramento State, n/d]

Wasting in biological OWRS involves the removal of excess biomass (sludge) from the bioreactor to maintain optimal microbial activity and system performance. Some of the key considerations to take into account include the following:

- Purpose of wasting
    - Control biomass concentration: Prevents overgrowth of microorganisms, ensuring efficient treatment.
    - Maintain system stability: Balances microbial population, preventing issues like sludge bulking and poor settling.
- Wasting rates
    - Determination: Based on the system's Solids Retention Time (SRT) and MLSS concentration.
    - Typical rates: Vary depending on system design and influent characteristics, generally ranging from 0.5% to 2% of the total reactor volume per day.
- Operational practices
    - Regular monitoring: Track MLSS and SRT to adjust wasting rates as needed.
    - Automated systems: Use automated controls to optimize wasting schedules and ensure consistent performance.

By effectively managing wasting and wasting rates, biological OWRS can maintain high treatment efficiency and system stability. [EPA, July 2024]

Food/microorganism ratio

The F/M ratio is a process control number that helps you to determine the proper number of microorganisms for your system. To do this calculation, you will need the following information:

- Influent Flow into your activated sludge system (Flow MGD)
- Influent CBOD (mg/l) concentration into your aeration tank
- Mixed Liquor Volatile Suspended Solids Concentration (mg/l)
- Volume (in gallons) of your aeration system

The term Food to Microorganism Ratio (F/M) is actually a measurement of the amount of incoming food (lbs of Influent CBOD) divided by the lbs of Microorganisms in your system. Some calculations also include the volume of activated sludge in your clarifiers; the one demonstrated here does not. If you have an activated sludge system, you should determine your F/M ratio regularly.

To determine the amount of incoming food (F), you need to know the CBOD of the influent into your activated sludge (aeration) system. You also need to know the flow (MGD).

To calculate the amount of food, we do the following calculation:

F = Influent Flow (MGD) X Influent CBOD Concentration (mg/l) X 8.34

To determine the volume of microorganisms (M), you need to know the volume of your aeration system and you need to know the concentration of Volatile Solids in your aeration system (MLVSS) or Mixed Liquor Volatile Suspended Solids. (Refer to the NPDES Lab Manual, the Solids Chapter for more info on MLVSS).

To calculate the microorganisms, we do the following calculation:

M = Aeration System Volume (in Millions of Gallons) X MLVSS X 8.34

To Calculate the Ratio: F/M

Example:

Facility Flow = 1.2 MGD

Influent CBOD= 230 mg/l

1.2 X 230 X 8.34 = 2301.84 lbs Coming In

F= 2301

Aeration System Volume 250,000 gal / 1,000,000 = 0.25MG

MLVSS = 2500mg/l

0.25 X 2500 X 8.34 = 5215 lbs of Microorganisms under Aeration

M = 5212

2301/5212 = 0.44 F/M Ratio

[Pennsylvania DEP, n/d]

Hydraulic loading

The two hydraulic control variables for the primary influent are the flowrate and the number of tanks in service. Flow control is limited because most facilities accept flow as it enters. Some facilities have equalization basins to smooth diurnal flow variations. If these basins are available, influent flow can be diverted during high flow periods (e.g., storm events). Later, the stored wastewater can be pumped back to the primary clarifiers at a steady rate. Facility recycle flows should be timed to smooth rather than aggravate variable hydraulic loading of the primary treatment units. [WWTF 1 Ch4 p48 para3]

Formula:

Hydraulic Retention Time (HRT) represents the average time that water remains in a treatment tank or reactor. It is calculated using the formula:

$$HRT = \frac{V}{Q}$$

Where:

- **V = Volume of the tank (in gallons or cubic feet)**
- **Q = Flow rate of water entering the tank (in gallons per day or cubic feet per day)**

Question:

An onsite water reuse facility uses two types of tanks to manage and treat graywater:

- **Tank A** is a **rectangular tank** measuring 30 feet long, 20 feet wide, and 12 feet deep. It receives 2,500 gallons of graywater per day.
- **Tank B** is a **cylindrical tank** with a radius of 10 feet and a depth of 15 feet. It receives 1,800 gallons of graywater per day.

1. Calculate the volume of each tank in gallons.
2. Calculate the Hydraulic Retention Time (HRT) in days for each tank.

Answer:

Tank A (Rectangular)

- **Volume = 30 × 20 × 12 × 7.48 = 53,856 gallons**
- **HRT =** $\frac{\textbf{53,856 gallons}}{\textbf{2,500 gpd (flow Rate)}}$ **= 21.54 days**

Tank B (Cylindrical)

- **Volume =** $\pi \times 10^2 \times 15 \times 7.48$ **= 35,248.67 gallons**
- **HRT =** $\frac{\textbf{35,248 gallons}}{\textbf{1,800 gpd (flow rate)}}$ **= 19.58 days**

Solids retention time

Solids retention time (SRT) is defined as the average length of time in days that an organism remains in the biological treatment system. It's calculated by dividing the total pounds of MLVSS in the aeration system by the number of pounds of biomass wasted per day, or

SRT, days = Total MLVSS, lbs / Total MLVSS Wasted, lbs/d

The operator determines the operating SRT for the ONWS and maintains it through wasting the appropriate amount of excess biomass from the treatment system. In other words, the amount of biomass (MLSS) in the treatment system is controlled and maintained through solids wasting.

Operational problems may often be linked to inappropriate SRT. Young sludge (low SRT) may be related to an inadequate microorganism population or an excessive BOD load (high F:M). The cells become dispersed rather than flocculated, settleability is poor, and the effluent becomes turbid. In this condition, oxygen is used up quickly due to the high metabolism rate, and sludge production is high. One telltale sign of this condition is the production of huge amounts of a billowing white foam. At the other extreme, an old sludge (high SRT) may be related to operating with an excessive microorganism population. All of the influent BOD has been used up (low F:M) and a dense, greasy, brown foam may appear and accumulate in the aeration tank. The wasting rate should be adjusted in either of these circumstances, but drastic changes should not be made in wasting rates from one day to the next. [SME input]

Example problem:

Formula:

$$\textbf{SRT} = \frac{\boldsymbol{Reactor\ Volume\ (MG)}}{\textbf{Waste Sludge Flow Rate (MG)}}$$

Question:

An onsite water reuse facility operates an activated sludge system with the following parameters:

- **Flow Rate**: 1.5 MGD (Million Gallons per Day)
- **MLVSS** (Mixed Liquor Volatile Suspended Solids): 3,000 mg/L
- **Waste Sludge Flow Rate**: 0.1 MGD

Assume the reactor volume is equal to the daily flow rate.

Note: **Reactor volume** refers to the total volume of the aeration tank where microorganisms treat the wastewater.

In this example, we assume the reactor volume equals the daily flow rate (1.5 million gallons), which is a common simplification in training scenarios to represent a steady-state system.

1. What is the reactor volume in gallons?
2. What is the Solids Retention Time (SRT) in days?

Answer:

1. Reactor Volume = 1.5 × 1,000,000 = 1,500,000 gallons

Calculation steps for Question 2:

Reactor Volume = 1.5 × 1,000,000 = 1,500,000 gallons

Waste Activated Sludge Flow Rate: 0.1 x 1,000,000 = 100,000 gallons

2. $\mathbf{SRT} = \frac{\mathbf{1{,}500{,}000}\ \boldsymbol{gallons}}{\mathbf{100{,}000\ gallons}}$ **= 15 days** (← Answer)

Nitrification-denitrification cycle

Graywater and blackwater sources in ONWS can contain significant amounts of ammonia. Reducing ammonia is important because ammonia impacts the ability to have effective free chlorine disinfection. Nitrification is a biological process by which ammonia is sequentially oxidized to nitrite and then to nitrate. If an ONWS also requires that the resulting nitrate be removed, one treatment alternative is the process of denitrification, in which nitrate is reduced to nitrogen gas. Denitrification requires special organisms called denitrifiers that can metabolize nitrate when they are in an environment with low dissolved oxygen and a readily biodegradable carbon source. Without a denitrification treatment step, nitrate persists in the ONWS treated water effluent and can concentrate when the same wastewater is recycled over and over again through the ONWS.

pH

pH is a critical parameter in the operation of MBRs for ONWS. It influences microbial activity, membrane performance, and overall system stability.

- Impact on microbial activity
  - Optimal range: The optimal pH range for most biological processes in MBRs is between 6.5 and 8.0. Within this range, microbial activity is maximized, leading to efficient organic matter degradation.
  - Deviations: pH levels outside this range can inhibit microbial activity, reducing treatment efficiency and potentially leading to system instability.
- Impact on membrane performance
  - Fouling: Extreme pH levels can affect membrane fouling rates. Low pH can lead to increased biofouling, while high pH can cause scaling and inorganic fouling.
  - Membrane integrity: Prolonged exposure to extreme pH levels can degrade membrane materials, reducing their lifespan and effectiveness.
- Control strategies
  - Monitoring: Regular monitoring of pH levels is essential to maintain optimal conditions for microbial activity and membrane performance.
  - Adjustment: pH can be adjusted using chemical dosing (e.g., acids or bases) to maintain it within the desired range.
  - Buffering capacity: Ensuring the system has adequate buffering capacity can help mitigate pH fluctuations and maintain stable operation.

[Bhattacharyya, A. et al., 2022]

Dissolved oxygen (DO) levels

Dissolved Oxygen (DO) is a critical parameter in the operation of Membrane Bioreactors (MBRs) for OWRS. It directly influences microbial activity, sludge characteristics, and overall system performance.

- Impact on microbial activity
  - Optimal range: Maintaining DO levels between 2-4 mg/L is essential for optimal microbial activity. Low DO levels (<2 mg/L) can reduce microbial metabolism, leading to incomplete organic matter breakdown.
  - Nitrification: Adequate DO is crucial for nitrifying bacteria, which convert ammonia to nitrate. Low DO can inhibit nitrification, affecting nitrogen removal efficiency.
- Impact on membrane performance
  - Fouling: Low DO levels can lead to poor sludge settleability, increasing the concentration of fine particles that contribute to membrane fouling.
  - Transmembrane pressure (TMP): Maintaining optimal DO levels helps reduce fouling potential, stabilizing TMP and ensuring efficient filtration.
- Control Strategies
  - Monitoring: Regularly monitor DO levels to maintain them within the optimal range for microbial activity and membrane performance.
  - Aeration control: Use automated aeration control systems to dynamically adjust DO levels based on real-time data, optimizing energy use and treatment efficiency.
  - Oxygen uptake rate (OUR): Measure OUR to fine-tune aeration rates, balancing microbial activity and minimizing energy costs.

[Portico, n/d/]

6.3.2 Engineered wetlands

Engineered, or constructed, wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality. [epa.gov constructed wetlands p1 para1] Engineered wetlands are an alternative to MBRs. Compared to MBRs, engineered treatment wetlands require a larger footprint to achieve similar levels of treatment (e.g., BOD, TSS, total organic destruction) so they may not be a good option for an ONWS in a space-constrained setting. One of the reasons this type of treatment may be chosen is that it allows the ONWS to take advantage of the natural aesthetics of the wetlands to enhance the visual quality of the building and to serve as a visual public reminder that an ONWS is being used. In addition, wetland may have a significantly lower energy requirement than MBR systems. [NBRC ONWS Guidance Manual p35 para1]

Unlike MBRs, engineered treatment wetlands do not have an existing framework for pathogen reduction crediting. 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. Online monitoring or grab sampling to measure BOD, ammonia, TSS, TOC, and turbidity can verify the treatment system is performing as it should. [NBRC Guidance Manual Training Module 4-Biological Treatment]

Although engineered wetlands have not been widely used in ONWS, there are a few examples in the U.S. of engineered wetlands treatment systems and inform important lessons learned.

FIGURE 6.4: *Engineered wetland treatment system at Denver Water's headquarters* *[Photo credit: Denver Water. No public source. Permission to use given.]*

6.3.2.1 Operation and maintenance considerations

The wetland media can clog with biofilm, which can result in more frequent media cleaning and media replacement. Lateral pipes can be scoured with hydrogen peroxide to clear biofilms. If the settling tank does not have a direct connection to remove solids to the municipal sewer system, solids must be removed via a vactor truck. Chemical fertilizer use should be minimized with engineered wetlands.

6.3.3 Other types of biological treatment

For more information on the following treatments – activated sludge, sequencing batch reactor (SBR), moving bed bioreactor, fixed bed bioreactor – it is recommended that the reader enroll in either of the following courses: Fundamentals of WW Treatment or Operation of WW Treatment Plants provided by Sacramento State Office of Water Programs.

6.3.4 Aerobic vs anaerobic treatment

6.3.4.1 Aerobic treatment

The biological treatment processes covered in this section thus far, including suspended growth, attached growth, and hybrid suspended/attached growth, rely on oxygen-consuming microbes to remove contaminants from the source water, often referred to as aerobic treatment systems. These oxygen-consuming treatment processes are best suited for source waters with relatively low organic content. Aerobic treatment systems that incorporate mechanical aeration devices like mixers or diffusers require additional energy to operate. [SME (TR) feedback]

6.3.4.2 Anaerobic treatment

An anaerobic system for onsite water reuse is a treatment process that operates without oxygen to break down organic matter in wastewater. These systems are particularly effective for treating high-strength wastewater and can be used in various applications, including residential, commercial, and industrial settings.

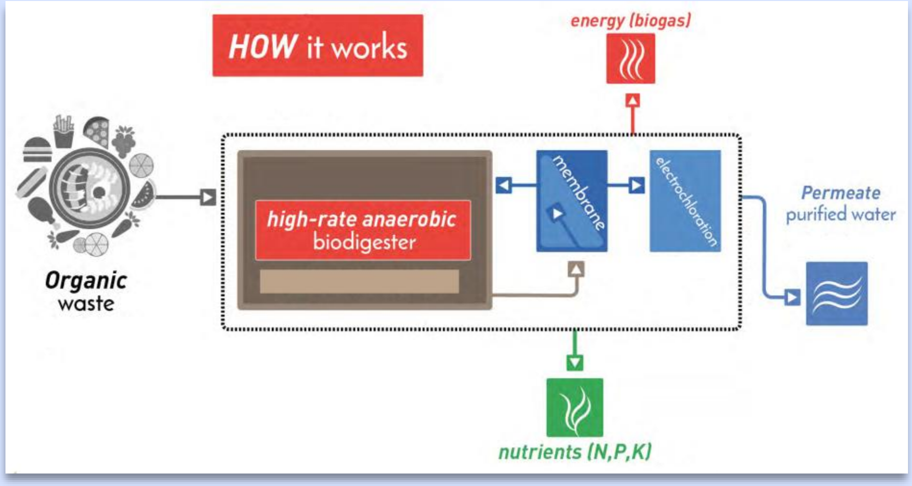

FIGURE 6.5: *Anaerobic treatment [Photo credit: University of S. Florida]*

Basic operation

- Pretreatment
  - Screening: Wastewater is first screened to remove large solids and debris.
  - Settling: The screened wastewater then enters a settling tank where heavier solids settle to the bottom, forming sludge.
- Anaerobic reactor: The pretreated wastewater flows into an anaerobic reactor, such as an Upflow Anaerobic Sludge Blanket (UASB) reactor or an anaerobic filter.
  - Microbial activity: In the absence of oxygen, anaerobic microorganisms break down organic matter, producing biogas (mainly methane and carbon dioxide) and reducing the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the wastewater.
  - Biogas collection: The biogas produced can be collected and used as a renewable energy source.
- Post-treatment
  - Effluent polishing: The treated effluent may undergo further treatment, such as aerobic polishing or filtration, to meet specific water quality standards for reuse.
  - Disinfection: The final step often involves disinfection (e.g., chlorination or UV treatment) to ensure the water is safe for its intended reuse applications.

Applications

- Non-potable uses: The treated water can be reused for non-potable applications such as irrigation, toilet flushing, and cooling tower makeup.
- Energy recovery: The biogas produced during anaerobic digestion can be used to generate electricity or heat, enhancing the sustainability of the system.

[WateReuse Association, Onsite and Decentralized Reuse, n/d]

6.4 Troubleshooting

6.4.1 Water quality issues that affect public health

There are potential contaminants in the water that can pose health risks, such as bacteria, viruses, and chemicals. As a result, the importance of regular testing and compliance with regulatory standards to ensure safe water quality must be emphasized. Issues to be taken into consideration include the following:

- Contaminants: Monitor for harmful contaminants such as bacteria (e.g., E. coli), viruses, and chemicals (e.g., lead, nitrates) that can pose health risks.
- Symptoms: Look for signs of waterborne illnesses, such as stomach pain, diarrhea, and other gastrointestinal issues.
- Prevention: Ensure regular testing and compliance with EPA standards to prevent contamination.

6.4.2 Common issues and remedies (i.e., biological and effluent issues)

There are some typical problems encountered in biological treatment and effluent quality, such as overloading, foaming, high TSS, and color/odor issues. These issues and their remedies are as follows:

- Biological issues:
  - Overloading: High BOD/COD levels can overload the system. Remedy: Adjust aeration rates and sludge wasting.
  - Foaming: Caused by excessive surfactants or filamentous bacteria. Remedy: Control surfactant levels and use anti-foaming agents.
- Effluent issues:
  - High TSS: Indicates poor filtration. Remedy: Check and clean membranes, optimize backwashing.
  - Color and odor: Caused by incomplete treatment. Remedy: Adjust treatment processes and ensure proper aeration.

6.4.3 Problem identification

It is important for operators and others working with an ONWS to be knowledgeable about methods for identifying issues in the system, including regular monitoring of key parameters, data analysis, and visual inspections. Early detection is important to prevent major problems.

- Monitoring: Regularly monitor key parameters such as pH, DO, BOD, TSS, and MLSS.
- Data analysis: Use data analytics to identify trends and potential issues early.
- Visual inspections: Conduct routine visual inspections of equipment and effluent quality.

6.4.4 Divert and investigate

There are steps that must be taken when an issue is detected, including diverting affected water to prevent contamination and conducting a thorough investigation to identify the root cause. As soon as an issue is detected, immediate action must be taken to divert affected water to a holding tank or bypass system to prevent contamination. Once done, it will be necessary to conduct a thorough investigation to identify the root cause of the issue, including sampling and testing.

6.4.5 Contact supplier/manufacturer

It is also important to know when and how to contact the system supplier or manufacturer for technical support and troubleshooting assistance. The system supplier or manufacturer should be contacted for technical support and troubleshooting assistance. Information on how to do so is commonly found in the Operations and Maintenance Manual. Once contact has been made, it will be necessary to provide detailed information about the issue, including system performance data and any recent changes.

6.4.6 Responsibility of employer/operator

The employer and the operator have different responsibilities when it comes to maintaining the system. Each must have proper training, be in compliance with regulations, and perform regular maintenance to ensure efficient operation.

6.4.6.1 Employer Responsibilities

- Training: Ensure operators are adequately trained and certified.
- Compliance: Maintain compliance with all relevant regulations and standards.

6.4.6.2 Operator Responsibilities

- Operation: Ensure the system operates efficiently and effectively.
- Maintenance: Perform regular maintenance and promptly address any issues.

UV system monitoring screen *[Photo credit: San Francisco Public Utilities Commission. No public source document. Permission to use.]*

Test Your Knowledge

Section 6: Biological Treatment

1. True or False. MBRs can take weeks or months to establish a stable population of microorganisms needed to meet treatment standards and complete commissioning.
   A. True
   B. False
2. Why is biological treatment used in an ONWS treatment train? (Select all that apply.)
   A. Increase operational reliability of downstream treatment processes
   B. Minimize color and odor issues
   C. To create hydraulic conditions to separate solids from the water
   D. Improve the reliability of pathogen reduction performance in downstream processes such as UV, chlorine, or ozone disinfection
3. What is the target level for biological oxygen demand (BOD) in the EPA's Guidelines for Water Reuse?
   A. ≤ 2 mg/L
   B. mg/L
   C. ≤ 10 mg/L
   D. ≤ 1 mg/L
4. Why is it important to keep total suspended solid (TSS) levels low?
   A. It is a cost-saving measure.
   B. It prevents irrigation pipes from clogging.
   C. High TSS levels can lead to membrane fouling, reducing the efficiency of the filtration process.
   D. It controls the amount of chemicals used.
5. Biological treatment systems include all but which of the following:
   A. Membrane bioreactor
   B. Engineered wetlands
   C. Vortex filter
   D. Fixed bed bioreactor

Public Safety Building in San Francisco, which has a rainwater harvesting system [Photo credit: San Francisco Public Works]

Section 7
Filtration

Filtration is a process in which suspended and colloidal particles in a liquid are removed by a physical process that allows the fluid to pass through but stops any solids. These physical processes include membrane filters (i.e., microfiltration and filtration), cartridge filters, and reverse osmosis. It is typically the fourth step in the treatment train process. See Figure 7.1. [NBRC ONWS Guidance Manual p36, para1; WWTF 3 Ch3 p2 para3]

Regarding size, the smaller the organism, the finer the filtration will need to be. For example, some protozoa can be removed with cartridge filtration, whereas viruses require reverse osmosis. [SME (TR) input]

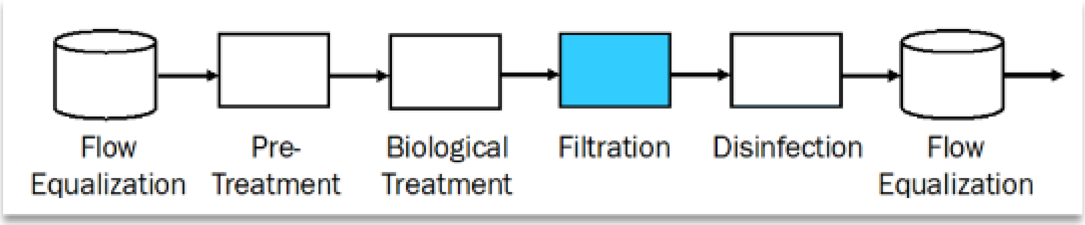

***FIGURE 7.1:** Filtration in a treatment train [NBRC ONWS Guidance Manual p36 Figure14]*

In this section, we will review the goals of filtration, the types of filtration, critical operating parameters, and membrane fouling.

7.1 Goals of filtration

The primary goal of filtration is to remove suspended and coarse solids, thereby protecting equipment downstream in the treatment train. [WWTF 3 Ch3 p2 para3; SME (TR) input]

Filtration has two primary benefits: 1) removing some pathogens and 2) removing particulates that may shield pathogens from effective disinfection downstream. [NBRC ONWS Guidance Manual p37]

Note that operators should consult with the O&M manufacturer's operation specifications and/or manuals.

7.2 Types of filtration

Typical filtration treatment technologies include:

- Bag filtration
- Cartridge filtration
- Media filtration
- Stormwater membrane treatment systems (non-biological)
- Reverse osmosis
- Membrane filtration

Let's review each type.

7.2.1 Bag filtration

A bag filter is a type of filtration device used in an ONWS to remove solid particles from water. It consists of a porous bag made from materials like nylon, polyester, or polypropylene, which is housed within a filter casing. Water flows through the bag, trapping solid particles while allowing clean water to pass through.

This helps protect downstream equipment, such as pumps and UV disinfection units, from clogging and damage. By ensuring that the water is free of larger particles, the bag filter enhances the overall efficiency and longevity of the water reuse system.

Maintaining bag filters in an ONWS involves several key considerations:

- Regular inspections: Check the filters periodically for wear and tear or clogging.
- Cleaning and replacement: Clean the filter bags as needed and replace them according to the manufacturer's recommendations to ensure optimal performance.
- Monitoring pressure: Keep an eye on the pressure differential across the filter; a significant increase indicates the filter needs cleaning or replacement.
- Proper disposal: Dispose of used filter bags in accordance with local regulations and environmental guidelines.

7.2.2 Cartridge filtration

Cartridge filters are pressure-driven separation devices that remove large particles by using replaceable filter elements housed in pressure vessels. In this process, water flows through the filter within the vessel, and particles collect on the filter surface, resulting in a drop in water pressure. The filter is replaced when the pressure drop reaches a predetermined level. [NBRC ONWS Guidance Manual p40 para3]

Cartridge filters are often placed between the booster pump and the high-pressure pump. This type of filter typically has a pore size of 1 µm and 5 µm. [WWTF 3 Ch6 p45 para4, p46 para1]

Cartridge filters are easy to operate and have a low energy footprint. However, they require more frequent replacement than membrane filters, and they receive lower pathogen credits. [NBRC ONWS Guidance Manual p41]

Maintaining cartridge filters in an ONWS involves several key considerations:

- Regular inspections: Periodically check the filters for signs of clogging or damage.
- Cleaning and replacement: Clean the cartridges as needed and replace them according to the manufacturer's recommendations to maintain optimal performance.
- Monitoring pressure: Monitor the pressure differential across the filter; a significant increase indicates the filter needs cleaning or replacement.
- Proper disposal: Dispose of used cartridges in accordance with local regulations and environmental guidelines.

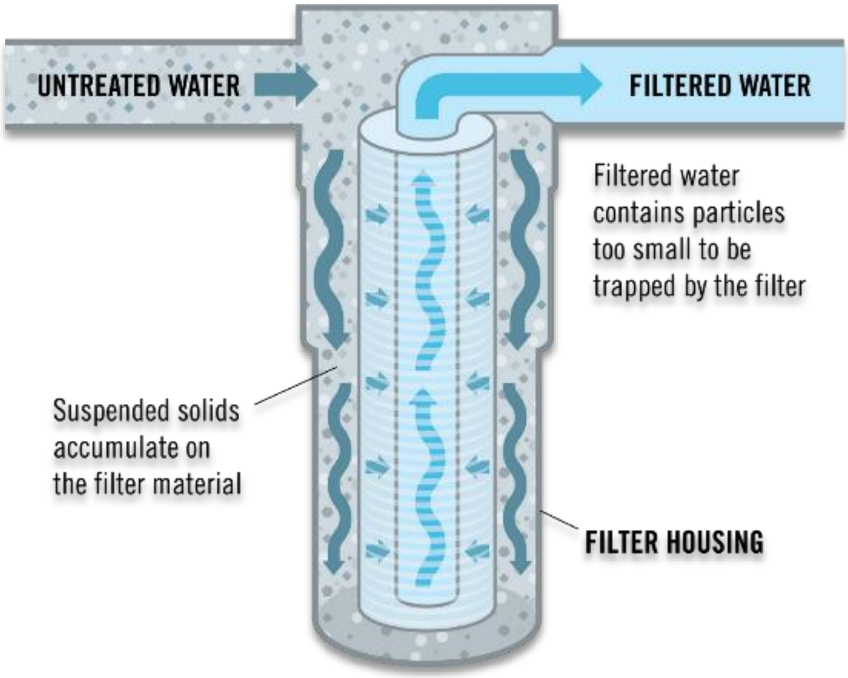

FIGURE 7.3: *Example of Cartridge Filter [Photo credit: UGA Cooperative Extension. Used with permission from authors]*

7.2.3 Media filtration

Media filtration is a physical removal process that effectively removes suspended particles from water. It provides a barrier against larger pathogen classes (e.g., *Giardia,* other protozoa) but is less effective at removing smaller pathogens (e.g., viruses). [NBRC ONWS Guidance Manual p58 para2]

Maintaining media filtration systems in an ONWS involves several key considerations:

- Regular inspections: Periodically check the filter media for signs of clogging or degradation.
- Cleaning and replacement: Clean the filter media as needed and replace it according to the manufacturer's recommendations to maintain optimal performance.
- Sediment removal: Remove accumulated sediment from the filter housing to prevent clogging and ensure efficient operation.
- Monitoring pressure: Keep an eye on the pressure differential across the filter; a significant increase indicates the filter media needs cleaning or replacement.
- Proper disposal: Dispose of used filter media in accordance with regulations and environmental guidelines.

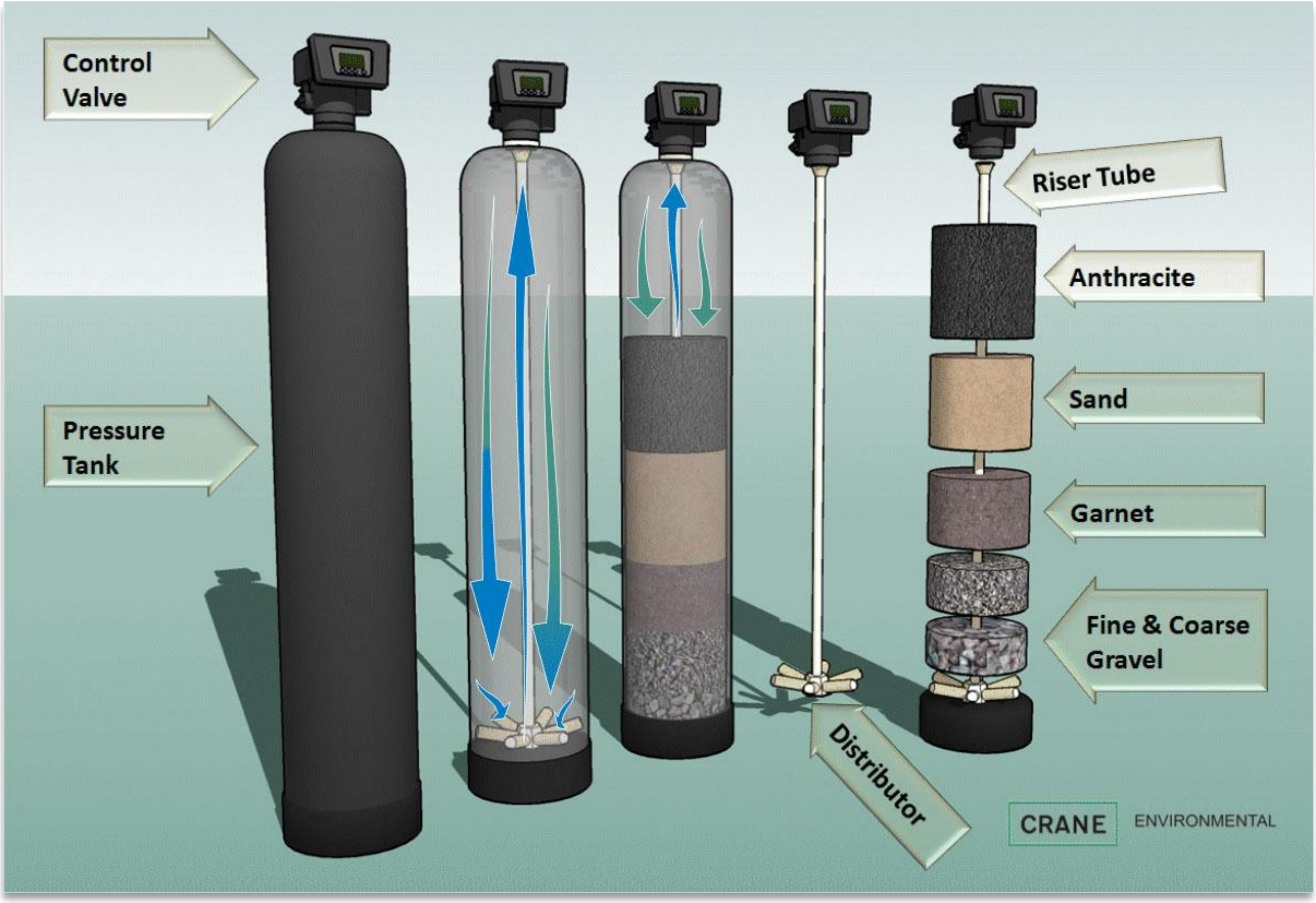

FIGURE 7.4: *Example of Media Filtration [Photo credit: Newterra procured Crane Environmental]*

7.2.4 Stormwater Membrane Treatment Systems (Non-Biological)

7.2.4.1 Overview

Non-biological membrane systems – such as **microfiltration (MF)**, **ultrafiltration (UF)**, **nanofiltration (NF)**, and **reverse osmosis (RO)** – provide physical separation of particulates, pathogens, and dissolved constituents without relying on microbial degradation. These systems are commonly used for stormwater polishing, final solids removal, pathogen reduction credits, and high-quality onsite reuse applications.

Because treatment performance depends entirely on hydraulics, membrane integrity, and consistent maintenance, operators must maintain stable pressure, flow, and cleaning regimes to prevent fouling and extend membrane life.

7.2.4.2 General Considerations for Non-biological Membrane Systems

Membrane Selection

- **MF/UF**: Best for particulate removal, turbidity reduction, and Log Reduction Targets. Nominal pore sizes 0.1–0.01 µm.
- **NF**: Provides partial softening, organics removal, and higher contaminant rejection than UF.
- **RO**: High-pressure membrane for dissolved solids, salts, metals, and trace organics.

Feedwater Requirements to maintain membrane performance:

- Turbidity < 1–5 NTU (system-specific)

- SDI (Silt Density Index) < 3–5 for NF/RO
- Minimal oils/grease—these permanently foul most membranes
- Stable pH and temperature within manufacturer limits

Pretreatment (e.g., cartridge filters, strainers, chemical conditioning) is often required.

Key Performance Indicators

- Transmembrane Pressure (TMP) or Differential Pressure (ΔP)
- Permeate Flow/Flux
- Turbidity of Filtrate
- Conductivity or TDS (NF/RO)
- Integrity Test Performance
- Cleaning Frequency & Chemical Consumption

Trending these KPIs is essential for identifying fouling and planning maintenance.

7.2.4.3 Membrane Fouling Mechanisms

Even without biological treatment, membranes can foul in several ways:

Particulate Fouling

- Caused by suspended solids, colloids, or inadequate pretreatment.
- Indicators: rising TMP/ΔP, declining flux.

Organic Fouling

- Natural organic matter (NOM), oils, surfactants.
- Indicators: gradual irreversible flux decline; color shift on membrane surface.

Scaling (NF/RO)

- Inorganic precipitation (e.g., $CaCO_3$, $CaSO_4$, silica).
- Indicators: rapid pressure increases, reduced recovery.

Chemical Degradation

- Due to incorrect pH, oxidants (e.g., chlorine on polyamide), or incompatible cleaning chemicals.

Compaction (RO/NF)

- Physical compression of membrane due to excessive pressure or warm temperatures.

7.2.4.4 Operations Requirements

Startup and Commissioning

- Confirm all pretreatment is operating correctly.
- Flush system with permeate or chlorine-free water.
- Verify pressures, flowrates, and temperature within manufacturer limits.
- Perform and record baseline integrity test (MF/UF).

Normal Operation –

- **Operators should:**
  - Monitor **TMP** at least daily (or continuously via SCADA).
  - Maintain **constant flux** whenever possible to reduce fouling.
  - Ensure **adequate crossflow velocity** (NF/RO) to limit solids deposition.
  - Verify pre-filter differential pressure to prevent membrane loading.

    - Track **permeate turbidity** (MF/UF) or **conductivity** (NF/RO) for quality assurance.

- **Alarm conditions typically include:**
    - TMP increase of **20–30%** from baseline
    - Filtrate turbidity > **0.1–0.3 NTU** (MF/UF)
    - Conductivity breakthrough for NF/RO
    - Cartridge filter pressure drop > manufacturer limit

7.2.4.5 Membrane Cleaning and Maintenance

Physical Cleaning

- Forward flush / feed flush: Removes loose solids.
- Backwash (MF/UF): Routine backwashing restores permeability; frequency typically every 20–60 minutes.
- Air Scour (UF): Enhances solids release during backwash cycles.

Chemical Cleaning (CIP)

Performed when TMP rise exceeds cleaning threshold or at scheduled intervals.

- **Typical CIP types:**
    - Alkaline detergents: organic fouling and oils
    - Acid cleaning: inorganic scaling
    - Oxidizing/Non-oxidizing agents: for specific foulant types (ensure compatibility with membrane material)
    - Enzymatic cleaners: for complex organic or proteinaceous fouling

- **Typical CIP Steps:**
    - Isolate membrane trains
    - Fill with cleaning solution
    - Recirculate at low pressure
    - Soak (1–6 hrs depending on fouling)
    - Rinse until neutral pH
    - Return to service and monitor TMP

Integrity Testing (MF/UF)

Required to verify barrier performance:

- Pressure Decay Test (PDT)
- Diffusive Air Flow Test (DAF)
- Bubble Point Test (hollow fiber)

Record pass/fail results and compare to manufacturer specifications.

Replacement Intervals

Typical membrane lifespan:

- MF/UF: **5–10 years**
- NF: **3–7 years**
- RO: **3–5 years**

Life depends heavily on pretreatment, chemical exposure, and fouling control.

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7.2.5 Reverse osmosis

Reverse osmosis (RO) is a membrane process that removes dissolved constituents by forcing water through a semi-permeable membrane. RO produces fresh water by applying pressure to a concentrated solution to force water to pass through a semipermeable membrane. This process results in a high-quality product stream (i.e., permeate) because it removes both inorganic and organic compounds, color, and odor-causing compounds. For an ONWS, this level of treatment may be typically unnecessary unless source water contains high levels of salts, organics, and color. [NBRC ONWS Guidance Manual p39 para2; WWTF 3 Ch6 p8 para1]

RO is also one of the most energy-intensive processes because it requires such a high feed pressure (>100 psi) as well as significant pretreatment. In addition, RO produces a waste brine stream that is typically 15%-25% of the volume of water treated, and managing these brine streams can be a significant barrier to sustainable use. [NBRC ONWS Guidance Manual p39 para2]

Maintaining reverse osmosis (RO) systems in an OWRS involves several key considerations:

- Regular inspections: periodically check the RO membranes and system components for signs of fouling, scaling, or damage
- Cleaning and replacement: clean the RO membranes as needed and replace them according to the manufacturer's recommendations to maintain optimal performance
- Monitoring performance: keep an eye on parameters such as permeate flow rate, pressure differential, and salt rejection rate; significant changes may indicate the need for maintenance
- Pretreatment maintenance: ensure that pretreatment systems, such as sediment filters and carbon filters, are functioning correctly to protect the RO membranes from damage
- Proper disposal: dispose of used RO membranes and other components according to local regulations and environmental guidelines

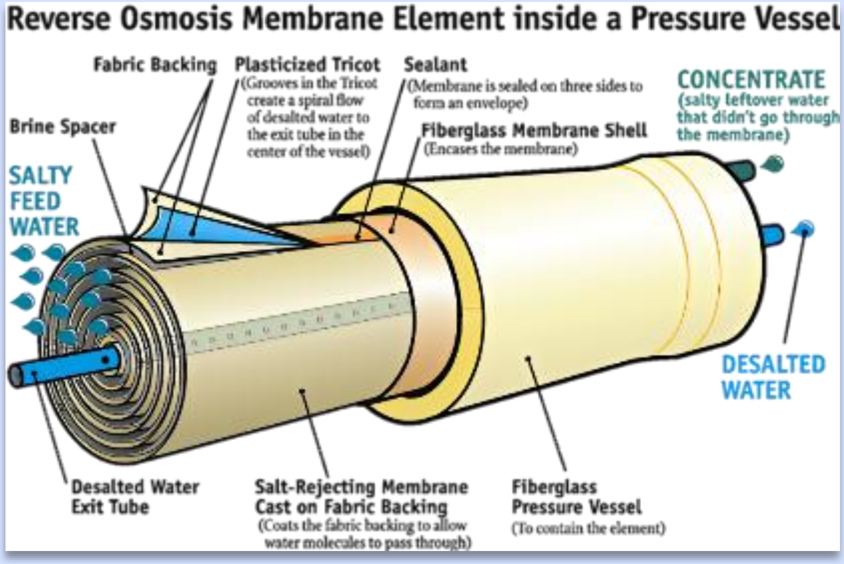

FIGURE 7.5: Example of RO Membrane [Photo credit: Stephen Lower Professor Emeritus of Chemistry, Simon Fraser University Burnaby/Vancouver B.C. Canada]

7.2.5.1 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.

7.2.6 Membrane filtration

Membrane filtration is a pressure-driven process that uses a membrane to sieve and remove particles and macromolecules. There are two main forms:

- Microfiltration (MF): pore size around 0.1 µm
- Ultrafiltration (UF) (e.g., hollow fiber, flat sheet): pore size around 0.01 µm

Membrane filters typically provide higher degrees of particulate removal, which leads to lower effluent turbidities. Additionally, the pore sizes of these filters are small enough to physically block larger-sized pathogens from passing into the effluent. Pumping is typically required for this type of filtration because they are pressure-driven. However, the larger energy needs are balanced because membrane filtration has a smaller footprint than other forms of filtration (e.g., media filtration). [NBRC ONWS Guidance Manual p37 para5, p38 para1]

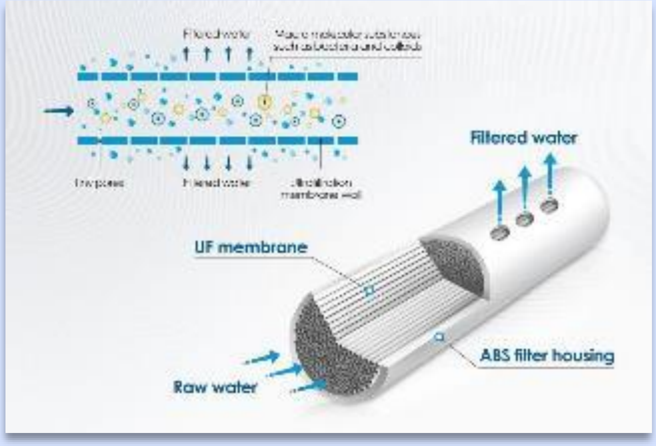

FIGURE 7.6: *Commercial membrane filtration system [Photo credit: Aquatiere]*

7.2.6.1 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. 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.

Maintaining membrane filters involves several key considerations:

- Regular inspections: periodically check the membranes for signs of fouling, scaling, or damage
- Cleaning and replacement: clean the membranes as needed using appropriate cleaning agents and replace them according to the manufacturer's recommendations to maintain optimal performance
- Monitoring performance: keep an eye on parameters such as permeate flow rate, transmembrane pressure, and overall system efficiency; significant changes may indicate the need for maintenance
- Pretreatment maintenance: ensure that pretreatment systems, such as sediment filters and screens, are functioning correctly to protect the membranes from damage
- Proper disposal: dispose of used membranes according to local regulations and environmental guidelines

7.3 Critical operating parameters of membrane bioreactors (MBRs)

7.3.1 Turbidity

Turbidity is suspended particulate matter measured by detecting scattered light and is involved with sand filtration, cartridge filtration, and membrane filtration. The presence of turbidity following the filtration process is indicative of a potential pathogen breakthrough. [WE&RF Final Report p59 Table6-5] Turbidity is a gross indicator of membrane performance. [WE&RF Final Report p93 para5] Excessive turbidity increases the probability of microorganisms escaping subsequent disinfection due to its effect. Successful treatment is dependent on proper coagulation (i.e., proper chemical doses and adequate mixing). [WWTF 3 Ch3 p8 para2]

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7.3.2 Pressure differential on membranes and filters

In an OWRS, pressure differentials across membranes and filters are critical indicators of system performance:

- Membranes: A high-pressure differential across a membrane indicates fouling or scaling, which reduces water flow and efficiency. Regular monitoring and maintenance are essential to prevent damage and ensure optimal performance.
- Filters: Similarly, a significant pressure differential across filters, such as bag or cartridge filters, suggests clogging. This can lead to reduced flow rates and increased energy consumption. Cleaning or replacing the filters as needed helps maintain system efficiency.

Maintaining appropriate pressure differentials ensures the longevity and effectiveness of the water reuse system, preventing operational issues and ensuring consistent water quality.

7.3.3 Transmembrane pressure

Transmembrane pressure is the main parameter for tracking fouling for hollow fiber membranes, and it is the difference between the feed pressure and filtrate pressure. [WWTF 3 Ch6 p27 para5]

7.3.4 Filter loading rates

Maintaining appropriate filter loading rates for membranes in a membrane bioreactor (MBR) is crucial for several reasons:

- Efficiency: Proper loading rates ensure the membranes operate efficiently, allowing for optimal filtration and consistent water quality.
- Fouling control: Maintaining the recommended loading rates helps minimize membrane fouling, which can reduce the frequency of cleaning and extend the lifespan of the membranes.
- System stability: Consistent loading rates contribute to the overall stability of the MBR system, ensuring reliable performance and reducing the risk of operational issues.
- Cost-effectiveness: By adhering to the manufacturer's design guidelines, operators can avoid unnecessary maintenance costs and downtime, making the system more cost-effective in the long run.

Filter loading rates for membranes in a membrane bioreactor (MBR) typically range around 25 liters per hour per square meter (LMH) of membrane area. This rate ensures efficient filtration while balancing permeate flow and membrane fouling. The mixed liquor suspended solids (MLSS) concentration in the MBR usually ranges from 10 to 12 grams per liter, optimizing the filtration process depending on the manufacturer of the membranes.

Always consult with the manufacturers recommended loading rates before determining efficient settings.

7.3.5 Membrane flux

Membrane flux is the rate of water transfer through the membrane surface and impacts the overall process economics, operating conditions, and number of membranes. [NBRC ONWS Guidance Manual p34 Table8]

Membrane systems operate best when they operate within a specific range of flux. A high flux means each module can produce more treated water, but the membrane can also foul quickly when the flux is too high.

Flux is calculated by using the following equation: $J = Q/A$.

In the equation:

J = volumetric water flux through membrane, $L/m^2 \cdot h$ or m/s (gallons per square foot per day, gpd/sq ft)

Q = flowrate, L/h (gpm)

A = membrane surface area, m^2 (sq ft)

[WWTF 3 Ch6 p15 para2]

7.3.6 Air scouring

Air scouring is a critical process in membrane bioreactors (MBRs) used for OWRS. It involves the continuous or intermittent injection of air bubbles into the membrane module to maintain membrane performance and longevity.

7.3.6.1 Purpose

- Prevent fouling: Air scouring helps to prevent the accumulation of biofilm, particulates, and other foulants on the membrane surface.
- Enhance mixing: The air bubbles promote mixing within the membrane tank, ensuring uniform distribution of biomass and reducing the risk of localized fouling.

7.3.6.2 Process

- Air injection: Air is introduced through diffusers located at the base of the membrane module.
- Bubble formation: The injected air forms bubbles that rise through the membrane fibers or plates.
- Shear forces: The movement of bubbles creates shear forces that dislodge foulants from the membrane surface.

7.3.6.3 Key benefits

- Improved membrane performance: Regular air scouring maintains high permeability and flux rates.
- Extended membrane life: Reducing fouling extends the operational life of the membranes.
- Energy efficiency: Optimizing air scouring can minimize energy consumption while maintaining effective cleaning.

7.3.6.4 Operational considerations

- Air flow rate: The air flow rate must be carefully controlled to balance effective cleaning with energy use.
- Frequency: The frequency of air scouring cycles depends on the fouling rate and system design.
- Monitoring: Regular monitoring of membrane performance and fouling indicators is essential to adjust air scouring parameters as needed.

By incorporating air scouring into the operation of MBRs, ONWS can achieve reliable and efficient treatment performance.

7.3.7 Solids loading (MLSS, TSS)

Solids loading refers to the amount of suspended solids that are introduced to the membrane surface in a membrane bioreactor (MBR). Proper management of solids loading is crucial for maintaining membrane performance and ensuring efficient operation of ONWS.

7.3.7.1 Key factors

- Mixed liquor suspended solids (MLSS): The concentration of suspended solids in the mixed liquor, typically ranging from 8,000 to 12,000 mg/L, affects the rate of fouling and overall system performance.

- Hydraulic loading rate: The volume of water passing through the membrane per unit area, usually measured in liters per hour per square meter (LMH), influences the solids loading rate.
- Solids retention time (SRT): The duration solids remain in the bioreactor, which impacts the biomass concentration and sludge production.

7.3.7.2 Operational considerations

- Membrane configuration: The design and arrangement of membranes (e.g., hollow fiber, flat sheet) affect how solids interact with the membrane surface.
- Air scouring: Regular air scouring helps to dislodge accumulated solids from the membrane surface, reducing fouling and maintaining permeability.
- Backwashing: Periodic backwashing with permeate or cleaning solutions can help remove fouling layers and restore membrane performance.

7.3.7.3 Challenges and solutions

- Fouling: High solids loading can lead to membrane fouling, reducing flux and increasing operational costs. Implementing effective cleaning protocols and optimizing operational parameters can mitigate fouling.
- Clogging: Solids accumulation can cause clogging within the membrane module. Ensuring proper pretreatment and maintaining appropriate MLSS levels can help prevent clogging.

7.3.7.4 Monitoring and control

- Regular monitoring: Continuously monitor MLSS, flux rates, and transmembrane pressure (TMP) to detect early signs of fouling and adjust operational parameters accordingly.
- Automated controls: Utilize automated control systems to optimize air scouring, backwashing, and chemical cleaning cycles based on real-time data.

By effectively managing solids loading, MBR systems in onsite water reuse applications can achieve reliable and efficient treatment performance, ensuring high-quality effluent for non-potable uses.

7.3.8 Membrane integrity testing

Membrane integrity testing assures the integrity of the filtration system, and it is crucial in ONWS to ensure the membranes are functioning correctly and effectively removing contaminants. This testing helps verify that the membranes are intact and capable of providing the necessary level of filtration, which is essential for maintaining water quality and safety. [WE&RF Final Report p94 Table 9-13]

There are two types of membrane integrity testing: direct and indirect. 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 the log reduction value (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 is 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.

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. [NBRC ONWS Guidance Manual p38-39]

7.3.8.1 Importance and relevance

Membrane integrity testing is important because it:

- Ensures water quality: Integrity testing confirms the membranes are effectively removing pathogens and other contaminants, ensuring the treated water meets safety standards.
- Prevents contamination: Detecting and addressing membrane breaches early prevents contamination of the treated water, protecting public health.
- Maintains system efficiency: Regular testing helps identify issues before they become significant problems, maintaining the overall efficiency and longevity of the water reuse system.
- Regulatory compliance: Many regulations require regular membrane integrity testing to ensure compliance with water quality standards.

7.3.8.2 Process description

The following processes occur during membrane integrity testing:

- Preparation: The membrane system is prepared by ensuring all components are properly installed and wetted.
- Testing method: Common methods include the pressure decay test, bubble point test, and diffusive flow test. These tests involve applying pressure to the membrane and measuring the response to detect any leaks or breaches.
- Data analysis: The results are analyzed to determine if the membrane is intact. Any deviations from expected results indicate potential issues that need to be addressed.
- Maintenance: If a breach is detected, the affected membranes are repaired or replaced to restore system integrity.

By regularly performing membrane integrity testing, operators can ensure the reliability and effectiveness of their OWRS, maintaining high water quality and compliance with regulatory standards.

7.4: Membrane fouling

Fouling of membranes will gradually occur and require cleaning. Here we will review the different types of fouling as well as the typical cleaning methods. [WWTF 3 Ch3 p55 para]; SME (TR/KJ) input]

7.4.1 Types of fouling

7.4.1.1 Biological

Biological fouling may occur especially in applications with relatively high TOC concentrations and inadequate levels of chloramines to suppress formation of biological films the membrane surfaces. [WWTF 3 Ch3 p55 para1]

Biological fouling in MBRs used for ONWS occurs when microorganisms, such as bacteria, form biofilms on the membrane surfaces. This biofouling leads to clogging of the membrane pores, reduced permeability, and increased operational costs due to higher energy demands and frequent cleaning.

Removal methods for biofouling include:

- Physical methods: Techniques like backwashing, air scouring, and membrane relaxation help dislodge and remove biofilms from the membrane surface.
- Chemical methods: Cleaning with chemicals such as sodium hypochlorite (NaClO) or citric acid can effectively remove biofilms, though care must be taken to avoid damaging the membranes.
- Biological methods: Strategies like quorum quenching, which disrupts the communication among bacteria, and the use of enzymatic agents to degrade biofilms offer environmentally friendly alternatives.

These methods can be used individually or in combination to maintain the efficiency of MBR systems.

7.4.1.2 Inorganic

Inorganic fouling of membranes in an OWRS occurs when minerals and other inorganic substances precipitate and accumulate on the membrane surface. Common inorganic foulants include calcium carbonate, calcium sulfate, silica, and metal oxides. This fouling reduces membrane efficiency by blocking pores and increasing resistance to water flow, leading to higher operational pressures and energy consumption.

Regular monitoring and maintenance, including periodic cleaning with appropriate chemicals such as citric acid and hydrochloric acid, are essential to manage inorganic fouling and maintain the system's performance.

7.4.1.3 Organic

Total organic carbon can indicate the presence of organic fouling. Total organic carbon can increase due to minor upsets in upstream biological treatment. Additionally, ONWS that use secondary effluent as feedwater may, at times, receive higher levels of TSS, which causes more fouling. Typically, once TSS concentrations are returned to normal levels, the fouling rate will decrease, and performance should stabilize with backwashes and not require chemical cleaning. It should be noted that once organic fouling forms on a membrane, it is more difficult to remove, and chemical cleaning is typically needed. As such, it is helpful for operators to measure TOC, iron, manganese, TSS, and turbidity levels in the feedwater to establish normal expected ranges and to correlate with normal long-term membrane performance. [WWTF 3 Ch3 p36 para1]

Fouling events are identified by a rapid decline in temperature-corrected specific flux and an increase in TMP. During these events, grab samples should be collected to determine which water quality parameters are outside of normal ranges. [WWTF 3 Ch3 p36 para1]

Operators will address organic fouling by chemical cleaning using sodium hypochlorite, combined with supplemental addition of sodium hydroxide. [WWTF 3 Ch3 p36 para1]

7.4.1.4 Physical

Physical fouling of membranes in an ONWS occurs when suspended solids, colloidal particles, and organic matter accumulate on the membrane surface. This buildup blocks the membrane pores, reducing water flow and increasing pressure differentials. Physical fouling can lead to decreased system efficiency, higher energy consumption, and more frequent maintenance.

Regular cleaning and pretreatment processes, such as sedimentation and filtration, help manage physical fouling and maintain membrane performance

7.4.2 Cleaning methods

7.4.2.1 Chlorination

Membrane manufacturers provide specifications concerning maximum exposure tolerance to free available chlorine (e.g., 1000 ppm*h). Additionally, feed water chlorine levels must be below detection limits (<0.02 mg/L). [WWTF 3 Ch3 p55 para1]

7.4.2.2 Acids/Bases

A mild CIP solution is typically attempted first to restore membrane performance. A high pH cleaning is typically followed by a low pH cleaning to remove scalants (e.g., calcium phosphate, calcium carbonate, sparingly soluble minerals). Occasionally, the order may be reversed. In addition, proprietary cleaning agents may be used to target specific scalants and foulants. It should be noted that there are commercial products that may provide a higher recovery of membrane performance than using manufacturer or industry recommended generic chemicals. [WWTF 3 Ch3 p55 para1]

San Francisco Skyline [Photo credit: San Francisco Public Utilities Commission. Permission to use]

Test Your Knowledge

Section 7: Filtration

1. What is the primary purpose of filtration?
   - A. Minimize growth of opportunistic pathogens
   - B. Remove particulates that may shield pathogens from effective disinfection downstream
   - C. Inject air into a tank
   - D. Help the operator keep track of inspections
2. What is one key consideration when maintaining bag filters?
   - A. The level of water in the storage tank
   - B. Filter placement
   - C. Use of an analyzer that can accurately measure both free chlorine and total chlorine
   - D. To keep an eye on the pressure differential across the filter; a significant increase indicates the filter needs cleaning or replacement
3. Typical filtration treatment technologies include all but which of the following:
   - A. Bag Filter
   - B. Media filtration
   - C. Engineered wetland
   - D. Reverse osmosis
4. To receive pathogen crediting for the use of a reverse osmosis system, what surrogate parameter must be continuously monitored?
   - A. BOD
   - B. Electrical conductivity
   - C. Flow
   - D. Potable makeup water
5. Why do you perform a pressure differential test on membranes? (Select all that apply.)
   - A. To test automated control systems and alarm functions
   - B. To encourage membrane fouling and poor performance
   - C. A high-pressure differential across a membrane indicates fouling or scaling, which reduces water flow and efficiency
   - D. A significant pressure differential across filters, such as a bag or cartridge filter, suggests clogging and means that cleaning or replacement of the filters is needed

The James R. Herman Cruise Terminal at Pier 27 [Photo credit: San Francisco Public Works]

Section 8 Disinfection

Disinfection refers to the destruction and/or inactivation of pathogenic microorganisms by exposure to a chemical agent or physical process. Disinfection is commonly used in ONWS and is typically accomplished in flow-through reactors, where a disinfectant is continuously added. [NBRC ONWS Guidance Manual p41 para1] In this section, we will examine some specific disinfection systems, including chlorine, UV, and ozone.

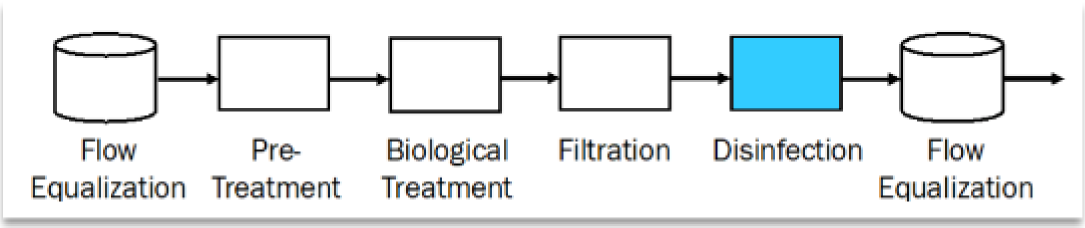

FIGURE 8.1: *Disinfection in a treatment train* [NBRC ONWS Guidance Manual p27 Figure9]

8.1 Chlorine disinfection

Chlorine is a disinfectant that is commonly used in drinking water, non-potable reuse, and potable reuse treatment. Chlorine can be used as a primary and/or secondary disinfectant. Several forms of chlorine are used, with the most common being 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, and as such, they will require a longer contact time for disinfection. As a result, and due to site constraints in most ONWS settings, large disinfection contractors are not feasible, so chlorine disinfection is limited to virus control. [NBRC ONWS Guidance Manual p42 para2, SME input]

8.1.1 Chlorine CT framework

The most commonly used disinfection framework is the CT framework, where CT refers to the product of the disinfectant residual concentration (C) and the contact time (T). [NBRC ONWS Guidance Manual p41 para10]

Operators must understand the CT framework, as it influences the design of chlorine contact tanks and the monitoring of chlorine residual to achieve pathogen reduction credits. To receive disinfection credit, chlorine contact tanks must meet the following three criteria:

- All water entering the chlorine contact tank must be chlorinated before entering the tank.
- Chlorine cannot be added in an internal recirculation loop (see the examples of inappropriate chlorine contact configurations in Figure 8.2).
- The chlorine residual must be measured in the effluent from the contact tank. Some potential configurations involving tank chlorine contactors are shown in Figure 8.2. [NBRC ONWS Guidance Manual p46 Figure17]

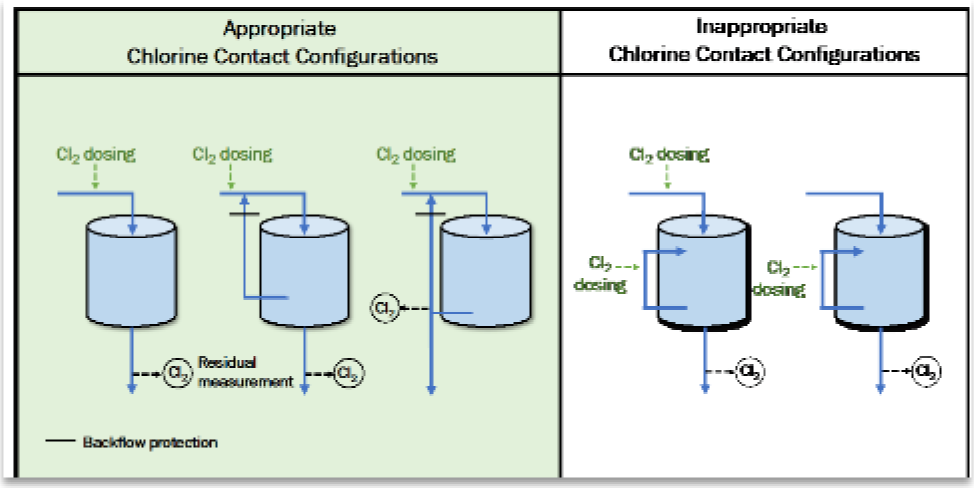

FIGURE 8.2: Example chlorine contact configurations using a tank [NBRC ONWS Guidance Manual p46 Figure17]

8.1.2 Free chlorine vs total chlorine

Chlorine residual can be measured through various methods, each of which measures either the free available chlorine (FAC) residual or the total chlorine residual (TCR).

Operators should be aware that analyzers that only measure free chlorine will not accurately measure a chloramine residual. However, if the analyzers measure total chlorine, operators should make sure the analyzer can accurately measure both free chlorine and chloramine residuals. Previous research has shown that not all analyzers claiming to be selective for free chlorine actually distinguish between free chlorine and chloramine. [SFPUC Onsite Water Reuse Program Guidebook p29]

In ONWS, free chlorine and chloramines are both used for disinfection, but they have distinct characteristics:

- Free Chlorine: This is chlorine in its uncombined form, known for its strong and rapid disinfectant properties. It effectively eliminates a wide range of pathogens quickly, but it is also less stable, requiring more frequent dosing.
- Chloramines: Formed by combining chlorine with ammonia, chloramines are more stable and provide longer-lasting disinfection. They produce fewer byproducts compared to free chlorine and are less likely to react with organic matter. However, chloramines are weaker disinfectants and may require higher concentrations to achieve the same level of pathogen control.

Choosing between the two depends on the specific needs of the water reuse system, including factors like the desired residual lifespan and the potential for byproduct formation. [pureflowz.com Understanding Chloramine and Free Chlorine p4 para1, p5 para1; ciwem.org Chlorination and Chloramination of Drinking Water p2 para4]

8.1.2.1 Chlorine guidance for offline periods

ONWS can experience offline periods for instances such as scheduled maintenance, low source water availability, or emergency shutdowns. During these periods, the building will rely solely on potable make-up water. Therefore, the chlorine residual recirculation pump should be shut down, and chlorine monitoring and boosting should stop. Potable makeup water should be the sole source of water provided to the building's non-potable distribution system.

- When transitioning to an offline period with chloraminated potable makeup water for systems that use a free chlorine residual in the treated water, it can lead to unstable residuals as free chlorine and chloramine residuals mix.
- Consider the following strategies to minimize the risk of chlorine residual loss as the storage tank and distribution system convert from free chlorine to chloramine:
    - During the transition, conduct frequent monitoring via online analyzers and grab sampling. Include samples throughout the building to ensure a residual is maintained.
    - Minimize the amount of water in the treated water storage tank before introducing a new residual by either drawing down the water or draining the tank.
    - Plan to make the transition to a new residual type during a normal or high-use period. This will reduce the amount of time the water stays in the treated water storage tank and will flush the new water through the distribution system. [SFPUC Onsite Water Reuse Program Guidebook p29]
    - Consider flushing the building plumbing [SME input]

8.1.3 Secondary disinfectant and proper distribution system management

Secondary disinfectant is used to maintain a disinfectant residual, preventing contamination as water travels through the distribution system. It protects against opportunistic pathogens, such as Legionella. [SFPUC Onsite Water Reuse Program Guidebook p27 col2 para1, p28 col1 para1, col2 para1]

Treated water must be properly stored and distributed to prevent compromising the quality of water after treatment. Opportunistic pathogens such as Legionella can grow in premise plumbing and cause illness, hospitalizations, and even death. New plumbing systems should not be allowed to stagnate before use (i.e., between construction and the time occupants use the system), nor should ongoing systems disregard best management practices until a significant biofilm mass develops. At this point, it is too late to control Legionella without regular and extensive cleaning protocols. Producing adequate, high-quality non-potable water that meets all pathogen control criteria is the first step in ensuring proper public health protection. The final step in quality control is to manage properly 1) storage and distribution systems and 2) the use of non-potable water. [Risk-based Framework for DNW Systems p61]

Different disinfectants offer advantages and disadvantages to overall water quality and distribution system management—generally, a higher disinfectant residual results in lower regrowth. The following information is not exhaustive, but it discusses best management practices for maintaining distribution systems. It is recommended that a free chlorine residual of 0.2 milligram per liter (mg/L) or monochloramine residual of 2 to 3 mg/L be maintained at or near the point of use (i.e., fixture farthest away from the ONWS) to control microbial growth. Using disinfectant booster stations within the distribution system is one way to ensure adequate disinfectant residuals for systems with long detention times. Chloramine provides a better residual duration than chlorine.

Additionally, periodic shock treatments with disinfectants and continuous disinfection looping of reservoirs help reduce the potential for regrowth and manage issues with biofilms. Stagnation resulting from dead zones or prolonged periods of zero-flow or low flow, which create long residence times and allow disinfectants to dissipate and sediments to deposit, should be avoided. This results in improved conditions for regrowth. [Risk-based Framework for DNW Systems p62]

8.1.4 Chlorine handling safety

FIGURE 8.3: A combined graywater and rainwater treatment system at 1550 Mission in San Francisco, California, uses chlorine to maintain a disinfectant residual to provide protection against opportunistic pathogens such as Legionella *[Photo credit: San Francisco Public Utilities Commission]*

Handling and Storage

- Store liquid chlorine (sodium hypochlorite) in a cool, dry, and well-ventilated area.
- Use appropriate containers made of materials resistant to chlorine corrosion.
- Ensure containers are tightly sealed to prevent leaks and evaporation.

Personal Protective Equipment (PPE)

- Wear gloves, goggles, and protective clothing when handling liquid chlorine.
- Use a respirator if there is a risk of inhaling chlorine fumes.

Usage and Application

- Follow manufacturer guidelines for dosing and application.
- Use automated dosing systems to ensure accurate and consistent chlorine levels.
- Monitor chlorine residuals regularly to maintain effective disinfection while minimizing the use of excess chlorine.

Health and Environmental Risks

- Chlorine is a strong oxidizing agent and can cause skin and eye irritation.
- Inhalation of chlorine fumes can lead to respiratory issues.
- Overdosing can harm aquatic life if discharged into natural water bodies.

Emergency Procedures

- Have an emergency plan in place for chlorine spills or leaks.
- Provide first aid measures for chlorine exposure, such as flushing eyes and skin with water.
- Ensure access to emergency showers and eyewash stations.

Regulatory Compliance

- Adhere to local and state regulations regarding the use and discharge of chlorine.
- Maintain records of chlorine usage and monitoring results to ensure accurate tracking.

By following these safety guidelines, you can ensure the safe and effective use of liquid chlorine in ONWS. Additional safety considerations are included in Section 14.

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8.1.5 Water quality considerations including reactions with ammonia (breakpoint chlorination)

In blackwater and graywater systems, ammonia may be present in the treated water. Ammonia presents a challenge for free chlorine disinfection. Ammonia will consume free chlorine and convert it to chloramine, a weaker disinfectant. A chlorine dosing control system can be used to breakpoint ammonia and ensure a free chlorine residual. Alternatively, chloramine can be used as a secondary disinfectant to simply blend with makeup water and avoid the breakpoint reaction. [SFPUC Onsite Water Reuse Program Guidebook p26,28]

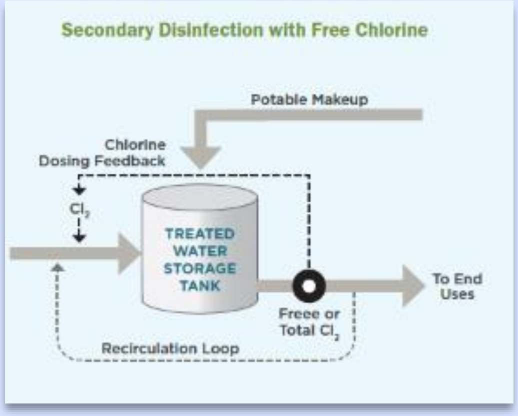

FIGURE 8.4: *Secondary disinfection with free chlorine*
[SFPUC Onsite Water Reuse Program Guidebook p28 Graphics]

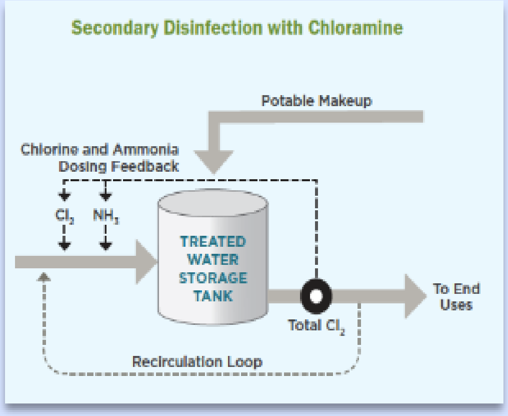

FIGURE 8.5: *Secondary disinfection with chloramine*
[SFPUC Onsite Water Reuse Program Guidebook p28 Graphics]

Free chlorine-specific meters for the verification of the appropriate residual concentration can be installed to address this issue. A second strategy is to implement reliable upstream control of the ammonia through nitrification. If done correctly, biological treatment can consistently reduce ammonia levels to below 0.5 mg/L. [NBRC ONWS Guidance Manual p43 para2,3]

Breakpoint chlorination is a process used in OWRS to achieve complete disinfection by adding chlorine to water until all ammonia and organic nitrogen compounds are oxidized. This process involves several stages:

1. **Initial chlorination**: Chlorine reacts with ammonia and organic matter, forming chloramines and other intermediate compounds.
2. **Chloramine formation**: As more chlorine is added, chloramines are formed, which provide some disinfection but are not as effective as free chlorine.
3. **Breakpoint**: When sufficient chlorine is added, it breaks down the chloramines and other compounds, leading to a sharp decrease in combined chlorine levels and an increase in free chlorine.
4. **Post-breakpoint**: Beyond the breakpoint, any additional chlorine remains as free chlorine, providing effective and residual disinfection.

This method ensures that all contaminants are neutralized, resulting in water that is safe for non-potable uses.

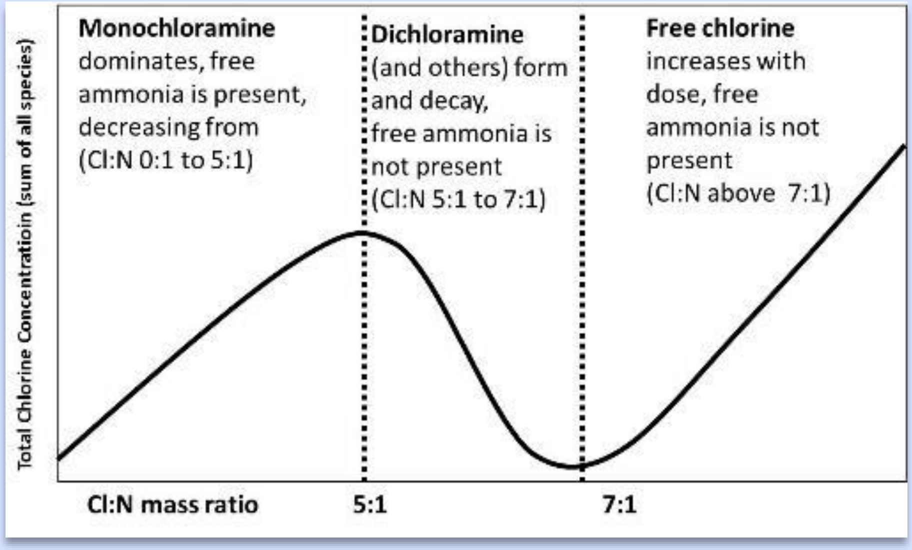

FIGURE 8.6: *Image of breakpoint curve [Photo credit: Florida Water Resources Journal]*

Regardless of how an ONWS controls ammonia, its reduction is a priority if disinfection with chlorine is used.

8.2 UV disinfection systems

Ultraviolet (UV) disinfection is a popular method of disinfection in the U.S. [WWTF 1 Ch10 p83 para1] because UV disinfection can provide significant protection against all classes of pathogens. UV systems also have a smaller footprint, no chemical requirements, and possibly more effortless operation because treatment is more resistant to water quality changes (e.g., ammonia bleed through). Based on these traits, it is a good choice for ONWS treatment trains. However, using UV disinfection successfully involves proper design and operation, which requires an understanding of the complexities of UV reactor validation and pathogen credit. [NBRC ONWS Guidance Manual p46 para1]

Two frameworks apply to an ONWS:

- EPA UV Disinfection Guidance Manual (UVDGM)
- NSF 55A standard for Ultraviolet Microbiological Water Treatment Systems [NBRC ONWS Guidance Manual p46 para1]

8.2.1 UV crediting framework based on UV dose

UV light irradiation is a commonly used disinfection process for drinking water, wastewater, and water reuse applications, involving the generation and transmission of UV light to inactivate pathogens. The primary mechanism of disinfection is the damage to nucleic acids, which 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.

The recommended dose-monitoring strategy is the UV Intensity Setpoint approach. The 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. 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, as the UV intensity reading will also reflect changes in UVT (i.e., lower UV intensity corresponds to lower UVT).

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. [NBRC ONWS Guidance Manual p47-48]

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, resulting in reduced 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 UVT will result in a decrease in measured UV intensity and, as a result, 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 traveling too fast through the reactor to guarantee that the desired dose is being achieved. – Low flows can also result in short-circuiting effects that can cause pockets of water to see very little UV light.

TABLE 8.1: *UV validation parameters and their importance [NBRC ONWS Guidance Manual p49 Table16]*

8.2.2 UV monitoring framework

For ONWS, the UV monitoring framework includes the following components:

- Regular monitoring: UV systems should be monitored regularly to ensure they are operating within the specified parameters. This includes checking UV intensity, flow rates, and water quality parameters.
- Performance validation: Periodic validation of the UV system's performance is essential. This involves testing the system to confirm it meets the required disinfection standards and adjusting settings as necessary.
- Maintenance and calibration: Routine maintenance and calibration of UV sensors and lamps are crucial to maintain system efficiency. This includes cleaning the quartz sleeves, replacing UV lamps, and calibrating sensors according to the manufacturer's recommendations.
- Data logging and reporting: Continuous data logging of UV system performance enables the tracking of trends and the identification of potential issues early. Regular reporting ensures compliance with regulatory requirements and helps in maintaining a record of system performance.
- Emergency procedures: Establishing clear emergency procedures for UV system failures or malfunctions is vital. This includes having backup disinfection methods and protocols for immediate response to ensure water safety.

Referring to the manufacturer's Standard Operating Procedures (SOP) is essential for specific guidelines and detailed instructions tailored to the particular UV system model. [NBRC ONWS Guidance Manual p45-48]

8.2.3 Safety

When working with UV light systems in onsite water reuse operations, safety is paramount. UV light, while effective for disinfection, can be harmful to operators if proper precautions are not taken. Here are some general safety guidelines:

- Personal protective equipment (PPE): Always wear appropriate PPE, including UV-resistant gloves, face shields, and protective clothing to prevent skin and eye exposure to UV radiation.
- System maintenance: Ensure the UV system is turned off and properly locked out before performing any maintenance or inspections to avoid accidental exposure.
- Training: Operators should receive thorough training on the safe handling and operation of UV systems, including emergency procedures in case of accidental exposure.

Referring to the manufacturer's Standard Operating Procedures (SOPs) is crucial for adhering to specific safety and maintenance guidelines. These SOPs provide detailed instructions tailored to the particular UV system model, ensuring safe and effective operation. They cover aspects such as routine maintenance schedules, troubleshooting, and emergency protocols, helping to maintain system efficiency and operator safety.

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8.3 Ozone disinfection (including susceptibility of reference pathogens)

Ozone disinfects wastewater by oxidizing the cell wall, cellular bonds, and nucleic material of bacteria, viruses, protozoa, and other microorganisms, and it produces radical by-products that also cause damage and destruction of microorganisms as well as CECs. [WWTF 3 Ch5 p3 para1]

Ozone is used for color removal; inactivating viruses, *Giardia,* and *Cryptosporidium*; and oxidizing and breaking down organic matter.

Ozone disinfection systems have four main components:

- A gas feed system
- An ozone generator
- An ozone contactor
- An off-gas destruction system

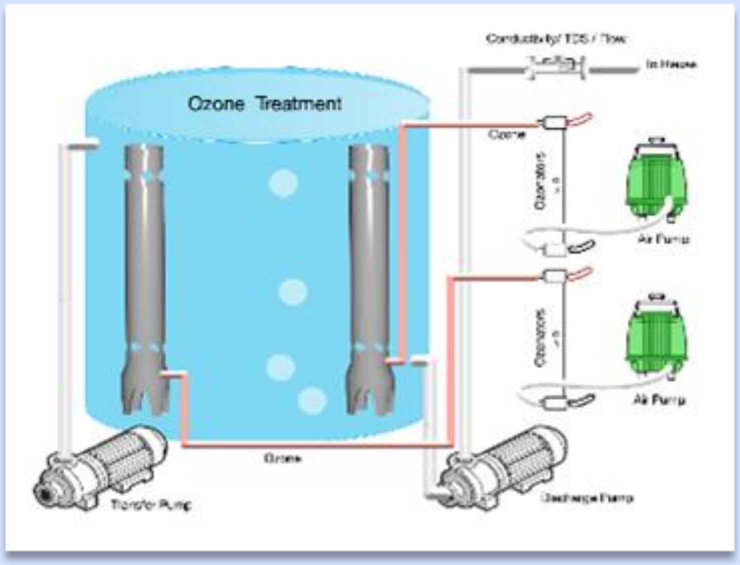


FIGURE 8.7: *Ozone disinfection system [Photo credit: CleanBlu Innovations]*

The gas feed system provides a source of oxygen to the generator, which generates ozone that is then delivered to into the contactor. Most of the ozone gas will be dissolved into the water, but some will be released from the contactor as off-gas. This off-gas should be captured and destroyed so that it does not escape into the surrounding room or environment because it can be toxic. [NBRC ONWS Guidance Manual p51 para2]

8.3.1 Ozone CT (disinfectant concentration x contact time) pathogen

Ozone pathogen crediting is based on the CT framework and, as a result, requires measurement of both the ozone residual concentration and the contact time. A main difference is that chlorine is typically injected in liquid form, while ozone is injected as a gas and time is needed to dissolve it into the liquid. Additionally, ozone reacts quickly in water and the residual can decrease very quickly along the length of the contactor. The time needed to effectively mix the ozone into the water and the time required for ozone to dissolve are not included in the defined period of contact time used for calculating the ozone CT. [NBRC ONWS Guidance Manual p51 para3]

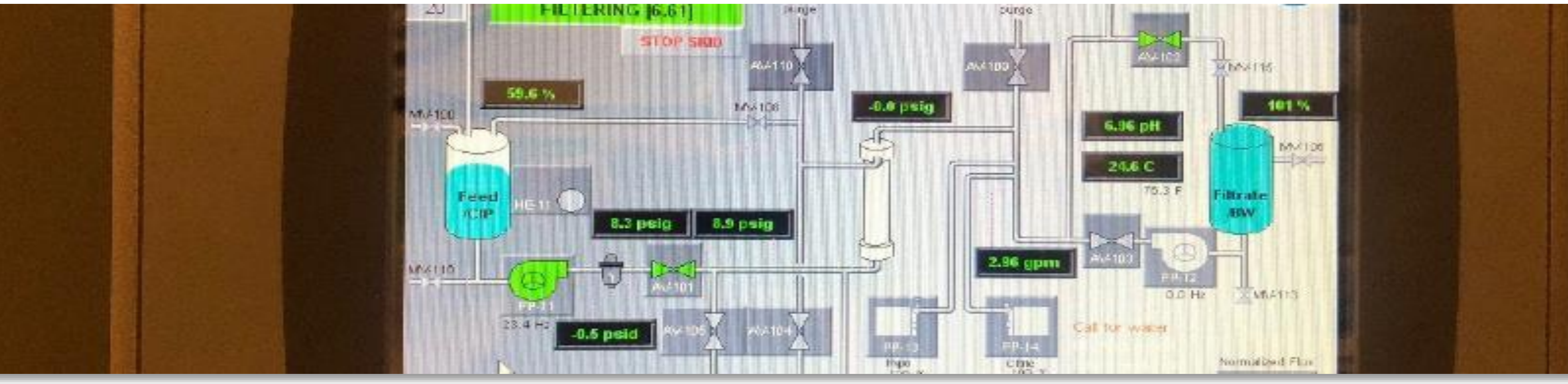
8.3.2 Ozone monitoring

It should be noted that there are currently no CT tables linking ozone dose to bacterial inactivation, so it is not recommended to grant bacteria inactivation credit based on the CT framework. At this point, effluent coliform monitoring should be used to demonstrate ozone performance. [NBRC ONWS Guidance Manual p52 para1]

8.3.3 Ozone handling safety

Safety is an important consideration for ozone, particularly in an ONWS. At a municipal level, ozone is typically isolated from the rest of the treatment system, either in its own room or in a separate building. However, in an ONWS, this is often not feasible due to space constraints. Since ozone processes can create significant heat and potential ozone gas leaks, there need to be more stringent considerations for ventilation and air exhaustion.

Ambient ozone monitoring should be included in an ONWS because ozone is very dangerous above fairly low concentrations, and an alarm should be set for an ambient ozone concentration of 0.1 mg/L. Local building and fire codes may provide further guidance and should be reviewed. [NBRC ONWS Guidance Manual p52 para2]

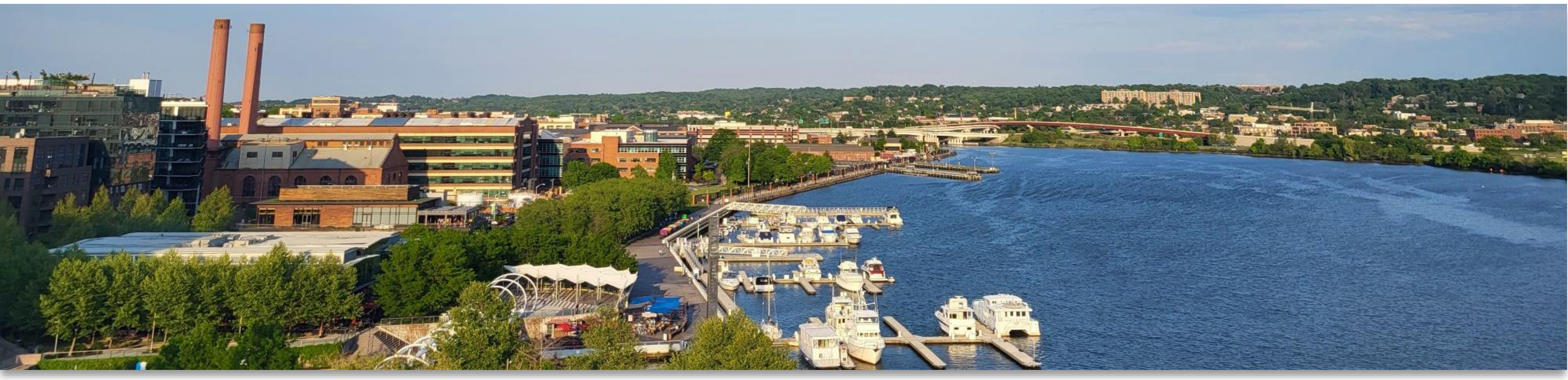


Example of a human machine interface (HMI) screen operators use to monitor the ONWs [Photo credit: San Francisco Public Utilities Commission. Permission to use.]

Test Your Knowledge

Section 8: Disinfection

1. What are the typical forms of disinfection used in ONWS? (Select all that apply.)
   A. Chlorine
   B. Membrane bioreactor
   C. Ultraviolet light
   D. Ozone
2. What is an advantage of using free chlorine vs chloramines?
   A. It effectively eliminates a wide range of pathogens quickly.
   B. It is more stable and provides longer-lasting disinfection.
   C. It produces fewer by-products.
   D. It is less likely to react with organic matter.
3. What is the purpose of secondary disinfection?
   A. Prevents accidental chemical spills
   B. Limits the growth of viruses
   C. Protects against opportunistic pathogens
   D. Minimizes particulates in the water
4. What is not a typical UV validation parameter?
   A. UV intensity
   B. Flow rate
   C. UV energy consumption
   D. UV transmittance
5. When is breakpoint chlorination used?
   A. To ensure chemical containers are tightly sealed to prevent leaks and evaporation
   B. When ammonia is present in the treated water
   C. For validation testing of the chlorine contactor
   D. To slow the flow of water through the chlorine contactor
6. What are the considerations for handling ozone safely? (Select all that apply.)
   A. Keep ambient ozone concentrations above 0.1 mg/L
   B. Ignore building and fire codes
   C. Generate more ozone
   D. Monitor for ambient ozone
   E. flow and efficiency
   F. A significant pressure differential across filters, such as bag or cartridge filters, suggests clogging and means that cleaning or replacement of the filters is needed



View from the DC Water Headquarters building, which features a rainwater harvesting system and other sustainable elements [Photo credit: San Francisco Public Utilities Commission. No public source. Permission to use.]

Section 9
Monitoring Water Quality and Physical Parameters

For an ONWS to function correctly, operators must understand the source water characteristics and the water quality and physical parameters that need to be monitored to ensure public health protection. Doing so requires the operator to:

- Define and measure water quality and physical parameters
- Understand laboratory reports and manage the data
- Know source water quality differences
- Understand the principles and techniques for water quality monitoring
- Be able to calibrate and verify instruments

Let's review each of these skills.

9.1 Principles and techniques of water quality monitoring

9.1.1 Introduction

Continuous process verification and water quality sampling are the primary methods for monitoring water quality. The data procured needs to be logged, preserved for the prescribed period, and shared with the appropriate regulators and on-site team members. The recommended standard for pathogen removal and/or inactivation is to continuously monitor using microbial, chemical, or physical indicator(s) or surrogate parameter(s) that verify the results of each treatment process. It should be noted that some systems take water quality samples and use lab testing to ensure water quality. [NBRC Guidebook for Developing/Implementing Regulations for ONWS p12 col1 para1, col2 para1; SME (TR) input]

In addition, the recommended standard for ONWS is to produce non-potable water with an appropriate color that does not contain odors that may be considered a nuisance, be noncorrosive, and maintain chlorine residual in the distribution system. [NBRC Guidebook for Developing/Implementing Regulations for ONWS p13 col1 para1-2; SME (TR) input]

9.1.2 Purpose of the standard methods

The purpose of standard methods in lab analytics is crucial for ensuring the reliability and consistency of test results used in monitoring water quality. Here are the key reasons:

- Consistency and reproducibility: Standard methods provide a set of consistent procedures that help produce reproducible results across different labs and over time.
- Regulatory compliance: These methods support compliance with regulations, such as the Clean Water Act, by establishing approved procedures for analyzing wastewater components.
- Quality control: They ensure high-quality data by detailing specific analytical techniques and quality control measures, such as calibration verification and the use of control samples.
- Public health protection: These standards provide a scientific basis for assessing contamination and ensuring water safety, thereby protecting public health.
- Environmental monitoring: These standards support ecological analysis and pollution control by accurately determining the presence and concentration of contaminants in water.

[SME (RP) input from EPA Clean Water Act Analytical Methods]

9.1.3 Purpose of continuous or grab sample monitoring and instruments

9.1.3.1 Types of monitoring

Continuous monitoring

Continuous monitoring involves ongoing confirmation of an ONWS performance using sensors for constant observation of selected parameters, including surrogate parameters that are correlated with pathogen LRT requirements. [NBRC Guidebook for Developing/Implementing Regulations for ONWS p10 col1 bullets]

Some of the most common types of sensors include:

- Flow meters
- Online pH meters
- Dissolved oxygen (DO) meters
- Conductivity meters
- Oxidation-reduction potential (ORP) meters
- Total suspended solids (TSS) meters
- Nitrogen analyzers
- Chlorine residual meters
- Turbidimeters

These instruments are vital for monitoring onsite equipment and processes and confirming the treated water meets regulatory standards. [WWTF 2 Ch9 p21 para2; SME (TR) input]

Grab sample monitoring

Grab sample monitoring, also known as *individual* or *discrete sampling*, involves taking a sample to represent a single moment in time and is not mixed with any other samples. This sample will only represent conditions at the exact moment it is collected. Per the EPA, grab samples are collected over a period of 15 minutes or less. Grab samples are functional under the following situations:

- If the flow composition to be sampled is reasonably constant
- If the flow to be sampled occurs intermittently or for short periods of time
- Must be used if the constituents to be analyzed are unstable or cannot be preserved (e.g., temperature, pH, chlorine residual, DO, E. coli, total and fecal coliforms)

- For determining the minimum and maximum concentrations of something entering or leaving a treatment process, or for determining the immediate effect of a process change
- To identify the characteristics of “slug” discharges
- To study variations and extremes in a waste stream during a period of time

[WWTF 2 Ch9 p22 para1 + bullets]

9.2 Water quality and physical parameters

9.2.1 Water quality parameters and measurements

Water quality parameters that need to be monitored by operators include DO, pH, turbidity, UV dose and transmittance, ORP, chlorine residual, and E. coli.

Water quality sampling should follow standard operating procedures (SOPs) and adhere to quality assurance (QA)/quality control (QC) protocols.

9.2.1.1 DO

DO is tracked in the biological treatment stages to ensure sufficient aeration for the microbes to consume the biochemical oxygen demand (BOD). [SME (TR, RP) input]

- Can be measured at discrete points in time or continuously
- Can be measured using monitoring sensors, which allow assessment of DO changes throughout the day and are cost-effective
- Can be measured using water quality probes, which report DO measurements in both mg/L and percent saturation

A typical range for DO concentration is 2-4 mg/l. [SME (TR, RP) input]. However, concentrations of DO can vary greatly, ranging from 0 mg/L to as high as 12 mg/L or more. Low DO concentrations are considered hypoxic, while DO concentrations below 0.2 mg/L are often regarded as anoxic (i.e., virtually no oxygen). [Dissolved Oxygen 2021 p4 col1 para1]

9.2.1.2 pH

pH is the concentration of hydrogen ions (H+) measured to determine the acidity of the water and is an essential indicator of chemical, physical, and biological changes in the water. [pH 2021 epa.gov p1 para1-2] In general, pH is the numerical expression of the relative intensity of the acidity or basicity of water. It is based on a scale that goes from 0 to 14 with the following parameters:

- A pH of 7 is neutral.
- A pH below 7 is acidic.
- A pH above 7 is basic.

The pH can be measured either colorimetrically or electrometrically. It should be noted that the electrometric method is more accurate than the colorimetric method and, as such, is preferred. When measuring pH, operators should only use pH probes equipped with temperature compensation. [WWTF 2 Ch9 p72 para1, p73 para1-2] Most regulatory requirements give this range as the acceptable threshold for pH. [SME (RP) input]

- Can be measured using a water quality probe, indicator tests, or strips
- Should be measured along with alkalinity [pH 2021 p3 col1 para1]
- Optimum pH range: maintaining pH between 6.5 and 8.5 for effective microbial activity and to reduce fouling
- Regular monitoring: consistent monitoring to ensure pH stays within the desired range
- Adjustments: use of pH adjustment chemicals to maintain optimal conditions

9.2.1.3 Turbidity

Turbidity is a measure of water clarity. If the water is high, it will appear cloudy or muddy. [Turbidity 2021 p1 para1] In an ONWS, turbidity is a surrogate for membrane integrity and is one of the most common methods to monitor system performance in membrane systems. The operator should check their permit and consult with their jurisdiction's regulatory requirements to establish this upper limit. [SME input]

FIGURE 9.1: *Example of a turbidity sensor [Photo credit: San Francisco Public Utilities Commission. No public source. Permission to use.]*

- Measurement: is measured directly using a turbidity meter or sensor (nephelometry)
- Reporting: is reported in nephelometric turbidity units (NTUs) [Turbidity 2021 p3 col1 para1, col2 para1]
- Target turbidity levels: keep turbidity levels below 0.1 NTU for optimal MBR performance
- Frequency of monitoring: continuous monitoring using online turbidimeters for real-time data
- Impact on membrane performance: high turbidity can cause membrane fouling, reducing efficiency and lifespan
- Water quality: low turbidity is essential to ensure treated water quality meets non-potable reuse standards; lower turbidity levels are necessary to minimize the presence of particulate matter and pathogens
- System maintenance: consistent turbidity control minimizes the need for frequent maintenance and cleaning
- System efficiency: helps optimize the overall process by providing real-time data on water quality, thus allowing timely adjustments to operating parameters
- Regulatory compliance: maintaining appropriate turbidity levels helps in adherence to local and international water quality regulations, ensuring safety and reliability of the treated water [SME (TR, RP) input]

9.2.1.4 UV dose

The UV dose is the UV energy per unit area incident on a surface, typically reported in units of mJ/cm^2 or J/m2. The UV dose received by a waterborne microorganism in a reactor vessel accounts for the effects on UV intensity of the absorbance of the water, absorbance of the quartz sleeves, reflection and refraction of light from the water surface and reactor walls, and the germicidal effectiveness of the UV wavelengths transmitted. It is essential to understand the value's significance and its relationship to the flow rate. [SME (IAMPO) input]

- Target UV dose: maintain a specific UV dose, typically measured in millijoules per square centimeter (mJ/cm^2), to ensure effective disinfection (consult local jurisdiction for target)
- UV dose calculation: calculate UV dose using the formula"
  - UV Dose (mJ/cm^2) = UV Intensity (mW/cm^2) × Exposure Time (seconds)
- Measurement methods: online UV sensors and dose monitoring devices to provide real-time data
- Frequency of monitoring: continuous monitoring to ensure consistent UV dose delivery

9.2.1.5 UV Transmittance (UVT)

UV transmittance (UVT) is the percentage of UV light that passes through a water sample, indicating the clarity of the water and assessing the efficiency of UV disinfection in water treatment systems. Higher UVT means more effective disinfection. [SME input, EPA.gov]

- Target UVT values: Operators should aim for high UVT (expressed as a percentage) to ensure the effective penetration of UV light, typically above 85% for optimal performance.

- Measurement methods: Operators must use UVT analyzers or monitors to measure the amount of UV light passing through the water.
- Importance of UVT: High UVT levels are crucial because particulate matter and dissolved organics can decrease UV Transmittance, reducing the effectiveness of the UV dose.
- Frequency of monitoring: Continuous or frequent tracking is used to detect and address variations in water quality.

9.2.1.6 Oxidation-reduction potential (ORP)

ORP is the activity or strength of oxidizers and reducers in relation to their concentration. If the ONWS uses ozone for disinfection or chlorine, then ORP will be a good measurement to gauge the effectiveness of the disinfectant. Operators need to understand where and how it is measured, as well as the required levels. [SME (IAMPO) input]

- Is measured off an inline probe or as a grab sample with a handheld probe

NOTE: A handheld probe must be used if ozone is the disinfectant being used. [SME (IAMPO) input]

9.2.1.7 E. coli

E. coli is a type of bacteria that lives in the intestines of people and animals. It is commonly found in human and animal feces, and while most strains are harmless, some can make people sick. [E. coli 2021 p1 para1] *E. coli:*

- Is measured by analyzing bacterial growth in laboratory analyses
- Is commonly measured by the IDEXX methods or the membrane filter procedure, although color test kits have also been EPA-approved
- Requires careful collection (using clean gloves and ensuring the container and lid are not touched with bare hands or dirty gloves) of water samples, as all sampling containers must be sterile [E. coli 2021 p2 col1 para1]

9.2.1.8 Total coliform

Total coliforms are a group of bacteria present in the environment, and most of them are not harmful to human health. However, these bacteria are not naturally present in groundwater, and their presence there indicates that more harmful organisms may also be present.

Fecal coliform and *E. coli* are subgroups within the total coliform group. The presence of *E. coli* indicates that the water has been contaminated with feces, posing an immediate risk to human health. [SME input; waterquality.montana.edu Total Coliform p1 para1]

9.2.1.9 Chlorine residuals

Free chlorine residual (FCR) is the amount of chlorine available to disinfect water, including hypochlorous acid (HOCl) and hypochlorite ions (OCl^-). It's the active form of chlorine that targets pathogens. The optimal range for FCR is 0.5 mg/l to 1.0 mg/l. [SME (RP, IAMPO) input] Total chlorine (TC) is the sum of free chlorine and combined chlorine (chloramine compounds formed when chlorine reacts with ammonia and organic nitrogen). It represents the total amount of chlorine present in the water. [SME (RP) input]

Key targets and measurement considerations for effluent chlorine residuals in ONWS:

- Target chlorine residuals: The goal is typically to maintain a measurable chlorine residual to ensure adequate disinfection. The specific target residual may vary by jurisdiction, but it is typically 0.5 mg/L and never less than 0.2 mg/L.
- Measurement methods: It is essential to use methods prescribed by entities like the EPA, which include titration, colorimetry, or online chlorine analyzers.
- Frequency of monitoring: Regular, often continuous monitoring is essential to promptly address any deviations in chlorine levels.

9.2.1.10 Pressure

- Monitoring pressures throughout the system is crucial for ensuring that each process operates optimally. For example, one key pressure to monitor is the transmembrane pressure, which represents the integrity and performance of the membrane filter.

9.2.1.11 Temperature

- Temperature affects a wide range of unit processes within a biological system.
- At colder temperatures, biomass settles more slowly, and microbial growth is slowed.

9.2.1.12 Flow

- Flow meters measure the rate of water flow into and out of the treatment system.

9.3 Advanced monitoring concepts

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Chlorine residuals

- DPD method: This method involves a colorimetric analysis where the DPD reagent reacts with chlorine to produce a pink color. Advanced spectrophotometers can measure the intensity of this color with high precision, providing accurate chlorine residual levels. Automated DPD analyzers can continuously sample and analyze water, ensuring real-time monitoring.
- Amperometric method: This method uses electrodes to measure the current generated by the reaction of chlorine with the electrode surface. Advanced amperometric sensors can provide continuous, real-time data and are often integrated into Supervisory Control and Data Acquisition (SCADA) systems for remote monitoring and control.

UV reactor monitoring

- UV intensity sensors: These sensors measure the intensity of UV light within the reactor. Advanced systems use multiple sensors placed at different points to ensure uniform UV exposure. Data from these sensors can be used to adjust the UV dose in real time, ensuring effective disinfection.

Pressure monitoring

- Pressure transducers: These devices convert pressure into an electrical signal that can be monitored continuously. Advanced transducers can detect minute changes in pressure, helping to identify issues like membrane fouling or blockages early.
- Differential pressure sensors: These sensors measure the pressure difference across the membrane, providing insights into membrane performance and fouling rates.

Turbidity monitoring

- Laser turbidity meters: These advanced meters use laser light to measure the scattering caused by suspended particles in the water. They offer high sensitivity and accuracy, essential for detecting low levels of turbidity that could indicate membrane fouling or breakthrough.

Temperature monitoring

- Digital temperature sensors: These sensors provide precise temperature readings and can be integrated into the control system to adjust operational parameters based on temperature changes. Maintaining optimal temperatures is crucial for biological processes and membrane performance.

BOD

Typical biological treatment processes remove 85%-95% of the organic matter measured as BOD, which is also a major contributor to turbidity, in blackwater. The design engineer should choose a biological treatment system that meets or exceeds the BOD, turbidity, and TSS treatment requirements as they have a significant impact on the design, cost, and performance of downstream treatment processes. Guidelines vary, with some saying that an ONWS should have BOD $\leq$ 10mg/L, while others say that BOD should not exceed an average of 10 mg/L and others require 25 mg/L. Operators should consult local regulations to establish the targets for BOD, TSS, Coliform. [NBRC ONWS Guidance Manual p32 para1; SFPUC Onsite Water Reuse Program Guidebook p18 para1] Overall, biological treatment is required for blackwater and graywater systems to meet the predetermined, approved level. Using biological treatment to reduce BOD and suspended solids will help:

- Improve the reliability of pathogen reduction performance in downstream processes (e.g., UV, chlorine, ozone disinfection)
- Increase operational reliability of downstream processes (e.g., membrane filtration, reverse osmosis, UV disinfection)
- Minimize issues with aesthetics (e.g., color, odor)
- Minimize regrowth of microorganisms (e.g., Legionella) in the distribution system [SFPUC Onsite Water Reuse Program Guidebook p18 para1+bullets]

Biological treatment technologies that can reduce BOD in an ONWS include:

- Membrane biological reactor
- Engineered wetland
- Sequencing batch reactor
- Moving bed biofilm reactor
- Conventional activated sludge
- Biofilter [SFPUC Onsite Water Reuse Program Guidebook p18 para2+bullets]

TSS

Typical biological treatment processes can effectively remove 85%-95% of total suspended solids (TSS), which are significant contributors to turbidity in ONWS. Selecting a biological treatment system that meets or exceeds the TSS, turbidity, and BOD treatment requirements is crucial, as they significantly impact the design, cost, and performance of downstream treatment processes. Guidelines vary, with some recommending TSS levels to be less than 10 mg/L, while others allow an average not exceeding 20 mg/L. Operators should consult local regulations to establish the targets for TSS, BOD, and coliform levels.

Overall, biological treatment is essential for both blackwater and graywater systems to meet required standards. Using biological treatment to reduce TSS and BOD will help:

- Enhance Filtration Efficiency: Efficient TSS reduction improves the performance of downstream filtration systems such as sand filters and activated carbon filters.
- Protect Membrane Systems: Reduced TSS helps in maintaining the efficiency and lifespan of membrane filtration systems by minimizing fouling.
- Reduce Sedimentation Issues: Lower TSS levels decrease the risk of sedimentation in storage tanks and distribution systems.
- Improve Aesthetic Quality: Reduction in TSS results in clearer water with less visible particles, enhancing the overall water quality for non-potable applications.

Biological treatment technologies that can reduce TSS in an ONWS include:

- Membrane biological reactor
- Engineered wetland
- Sequencing batch reactor
- Moving bed biofilm reactor
- Conventional activated sludge
- Biofilter

TDS

Typical biological treatment processes can effectively reduce total dissolved solids (TDS) levels, which are significant contributors to water quality issues. Choosing a biological treatment system that meets or exceeds TDS, turbidity, and BOD treatment requirements is crucial as they impact the design, cost, and performance of downstream processes. Guidelines vary, with some recommending TDS levels to be less than 300 mg/L. Operators must consult local regulations to establish targets for TDS, BOD, and other parameters.

Overall, biological treatment is critical for both blackwater and graywater systems to meet required standards. Using biological treatment to reduce TDS and BOD will help:

- Enhance reverse osmosis efficiency: lower TDS levels before reverse osmosis (RO) treatment reduce membrane fouling and increase the lifespan and efficiency of RO membranes.
- Improve effluent quality: reduced TDS improves the overall quality of treated water, making it suitable for non-potable uses such as irrigation and process water.
- Operational reliability: consistent TDS reduction enhances the operational reliability of downstream processes by preventing scaling and other issues.
- Environmental protection: lower TDS levels in effluent minimize the environmental impact of discharging treated water back into natural water bodies.

Biological treatment technologies that can reduce TDS in an ONWS include:

- Membrane biological reactor
- Engineered wetland
- Sequencing batch reactor
- Moving bed biofilm reactor
- Conventional activated sludge
- Biofilter

Reverse osmosis is highly effective in further reducing TDS, often achieving a TDS level of 10 to 50 parts per million (ppm). Biological pretreatment, like sequencing batch reactors (SBR), significantly enhances RO efficiency by reducing fouling, making it a promising combination for TDS removal

Dissolved oxygen (DO)

DO concentrations are crucial for the effective operation of on-site non-potable biological treatment systems, such as membrane bioreactors (MBRs). In these systems, DO levels directly impact the efficiency of microbial activity, which in turn influences the overall treatment process.

- Impacts
    - Microbial health: adequate DO levels ensure that aerobic microorganisms remain active and efficient in breaking down organic matter.

- System performance: Optimal DO concentrations improve the performance of biological processes, including nitrification and denitrification; insufficient DO can lead to incomplete treatment and potential issues with effluent quality.

- Optimal range
  - Typical range: For most biological treatment systems, maintaining DO levels between 2 to 4 mg/L is considered optimal. This range supports healthy microbial activity and efficient organic matter breakdown.
  - Monitoring and adjustment: Continuous monitoring of DO levels is essential; adjusting aeration rates or oxygen supply can help maintain DO within the desired range.
- Advantages of optimal DO:
  - Improved efficiency: Maintaining optimal DO levels can enhance the removal of pollutants, including TSS and BOD, leading to higher effluent quality.
  - Operational reliability: Proper DO management reduces the risk of system failures and ensures consistent treatment performance.

Legionella

Biological treatments to reduce BOD and suspended solids help to reduce Legionella. [SFPUC Onsite Water Reuse Program Guidebook p19 para1+bullets] Secondary disinfection is used to maintain a disinfectant residual to prevent contamination as water travels through the distribution system and provide protection against opportunistic pathogens, such as Legionella. [SFPUC Onsite Water Reuse Program Guidebook p27 col2 para1] In addition, wastewater heat recovery systems help control Legionella by cooling down the treated non-potable water being sent to toilets and other non-potable end uses in buildings. [SFPUC Onsite Water Reuse Program Guidebook p37 col2+bullets]

- Immunoassays: These tests use antibodies to detect Legionella antigens. Advanced immunoassays can provide rapid results and are highly specific, making them suitable for routine monitoring.
- qPCR/ddPCR: These methods are also used for Legionella detection, providing rapid and accurate quantification of Legionella DNA in water samples.

pH monitoring

- pH probes: Advanced pH probes use glass electrodes to measure hydrogen ion concentration. These probes can be calibrated automatically and provide continuous data, which is critical for maintaining the correct pH balance for biological activity and membrane integrity.

Bacterial analyses

- ATP monitoring: Advanced luminometers used in ATP monitoring can provide rapid results, often within minutes. This method is highly sensitive and can detect low levels of microbial contamination, making it ideal for real-time monitoring.
- Culture-based methods: Automated systems can incubate and count bacterial colonies, reducing human error and increasing throughput. These systems can also identify specific bacteria using selective media and biochemical tests.
- qPCR and ddPCR: These molecular techniques provide high sensitivity and specificity for detecting and quantifying bacterial DNA. qPCR can quantify DNA in real time, while ddPCR offers absolute quantification without the need for standard curves. These methods are essential for detecting pathogens like Legionella and E.coli.

Hardness monitoring

- Ion-selective electrodes (ISE): These electrodes measure the concentration of specific ions (e.g., calcium, magnesium) that contribute to water hardness. Advanced ISEs provide continuous, real-time data and can be integrated into control systems to adjust treatment processes.

Water level monitoring

- Ultrasonic level sensors: These sensors use ultrasonic waves to measure water levels in tanks and reactors. They provide accurate, non-contact measurements and can be used in harsh environments.
- Radar level sensors: These sensors use radar waves to measure water levels and are highly accurate, even in turbulent or foamy conditions.

Ozonation monitoring

- Ozone analyzers: These devices measure the concentration of ozone in water. Advanced analyzers use UV absorption or electrochemical methods to provide continuous, real-time data, ensuring effective disinfection without excessive ozone levels.

Flow meters

- Electromagnetic flow meters: These meters measure the flow rate of water using electromagnetic induction. They are highly accurate and can handle a wide range of flow rates, making them suitable for various applications in MBR systems.
- Ultrasonic flow meters: These meters use ultrasonic waves to measure flow rates and are ideal for non-invasive measurements. They can be used in both clean and dirty water applications.

By employing these advanced monitoring and analysis techniques, operators of onsite non-potable MBR systems can ensure high water quality, optimize system performance, and protect public health.

Parameter	Average	Maximum
BOD	<10 mg/L (4-week)	25 mg/L
TSS	<10 mg/L (4-week)	30 mg/L
Odor	The system should 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	

***TABLE 9.1:** Distribution system water quality goals* *[NBRC ONWS Guidance Manual p53 Table19]*

9.4 Basics of sampling techniques

Sampling is conducted through valved taps, and it is crucial that the taps are clean and free from any materials that could contaminate the sample. A different sampling device should be used at each sampling location, and each sampling should be labeled with the following information:

- Date
- Time
- Sample location
- Parameters to be analyzed
- Name of the collector

Collectors should always wear powder-free gloves and change them frequently during the process. Additionally, it is crucial to be mindful of hand placement and keep them away from the opening of the sampling device. [WWTF 2 Ch9 p32 para1-3]

When selecting sampling locations, operators must consider the type of information required from the sample. Typically, it is best to collect samples from well-mixed locations that are easily accessible and representative of the overall population. An effective sampling program is the basis of the monitoring and control program of an ONWS. [WWTF 2 Ch9 p13 para3-5]

9.4.1 Selection of sample taps

The two main types of water samples used for monitoring in an ONWS are grab samples and composite samples.

Grab samples are taken when specific information related to a specific sampling location, time, or distinct area is needed. This type of sample provides a snapshot of the water quality at the exact time and place where the sample was taken. There are two methods for obtaining a grab sample: dipping a sample bottle into the water or using a specialized sampling device. An operator will need to decide which of the two types of grab samples to use: discrete or depth-integrated. A discrete grab sample is taken at a specific location, depth, and time, and then analyzed for the desired pathogens. A depth-integrated grab sample is collected over a predetermined part or the entire depth of the water column at a selected location and time in a given body of water and then analyzed. Grab samples often require very little equipment, and there may be flexibility in choosing the sampling location, which can be advantageous. However, on the flip side, this type of sample may limit data resolution due to the smaller number of samples typically collected. [agriculture.canada.ca p1 para1-5]

Composite samples are taken when an average representation of a sampling location or time is needed. As the name implies, this is a composite of grab samples taken at different times or locations, which are then pooled together to create a single sample. A composite sample is helpful because it provides a picture of the average condition of the water over time or space. Additionally, this type of sample may be more cost-effective because it reduces the cost of analyzing a large number of samples. However, because composite samples are not individualized, there is no mathematical ability to assess the variability of the water. Additionally, some constituents (e.g., pH, DO tests) are not stable enough for the mixing process. In contrast, others (e.g., bacteria) require sterile sampling containers, which are difficult to provide with a composite sampling process. [agriculture.canada.ca p1 para6-7]

9.4.2 Collection of microbial samples

9.4.2.1 BOD

- Sampling procedure:
    - Collect samples in clean, sterile containers
    - Refrigerate immediately at 0-6°C
    - Ensure minimal exposure to air and light to prevent biological activity
- Hold time:
    - Maximum holding time is 48 hours

9.4.2.2 TSS

- Sampling procedure:
    - Collect samples in clean, high-density polyethylene (HDPE) containers
    - Refrigerate immediately at 0-6°C
- Hold time:
    - Maximum holding time is seven days

9.4.2.3 Coliform

- Sampling procedure:
  - Use sterile sample bottles provided by the laboratory
  - Avoid touching the inside of the bottle or cap
  - Use fresh powder-free gloves
  - Ensure the sample tap is disinfected
  - For non-metal taps, use isopropyl alcohol
  - For metal taps, a torch can be used to heat the sample port until bacterial contamination is mitigated
  - Collect samples from appropriate distribution points, avoiding sites with possible contamination
- Hold time:
  - Maximum holding time can range from eight to 30 hours, depending on the analysis

9.4.3 Determination of sample hold times

A sample hold time refers to the period between when a sample is collected and when it is analyzed. The length of time provided is based on the constituent of interest. However, samples should be analyzed as soon as possible to increase the accuracy of the analysis and minimize any potential for chemical, biological, or physical changes. [WWTF 2 Ch9 p44 para3] The operator should consult with the laboratory to determine sample hold times for accurate analysis.

9.5 Instrument calibration and verification

Regular calibration is essential for maintaining accurate and reliable readings in continuous monitoring instruments for onsite non-potable water treatment systems. Proper calibration ensures compliance with both industry standards and regulatory requirements.

9.5.1 pH probes

Calibration schedule:

- Weekly calibration: conduct calibration checks using buffer solutions, typically pH 4, 7, and 10
- Monthly maintenance: full calibration and thorough cleaning to ensure accuracy

9.5.2 DO probes

Calibration schedule:

- Weekly calibration: span calibration using a saturated air sample for accurate readings
- Monthly maintenance: check probe performance, clean if necessary, and recalibrate

9.5.3 Chlorine analyzers

Calibration schedule

- Weekly calibration: detailed calibration with primary standard solutions to ensure precise readings
- Monthly maintenance: inspect and clean electrodes, followed by a comprehensive calibration

9.5.4 Regulatory compliance and best practices

Adhering to the calibration schedules above helps maintain system efficiency and ensures accurate water quality monitoring. Compliance with local regulations and guidelines—such as those from the EPA and specific manufacturer recommendations—ensures reliable operation and precise readings.

Regular calibration following these schedules helps maintain system efficiency and compliance, ensuring the accuracy of critical water quality parameters. The calibration and compliance schedule should be included in the operations plan.

9.6 Laboratory reports

Effective operation of an ONWS relies heavily on the operator's ability to understand and manage water quality through laboratory testing and reporting. Laboratory reports are essential tools that provide insight into system performance, regulatory compliance, and operational troubleshooting.

Key objectives of laboratory reporting in ONWS

Operators must be able to:

Understand water composition

- Analyze the chemical, biological, and physical characteristics of:
  - Influent (incoming wastewater)
  - Effluent (treated water)
  - Internal process streams (e.g., membrane filtrate, bioreactor outputs)
  - Calculate loading rates

Determine organic and hydraulic loading rates to the overall facility and individual treatment units (e.g., MBRs, media filters, UV disinfection)

Collect and analyze samples

- Perform sampling for:
  - Process control (e.g., adjusting aeration or chemical dosing)
  - Regulatory compliance (e.g., meeting local health department standards)
  - Understand system components
- Interpret lab data in the context of:
  - Critical unit processes (e.g., biological treatment, filtration, disinfection)
  - Operational controls (e.g., backwash cycles, flow diversion valves)

Complete commissioning and sampling plans

- A comprehensive commissioning plan should include:
  - Sampling locations – clearly marked points for influent, effluent, and intermediate streams
  - Sampling frequency – daily, weekly, monthly, or event-based sampling schedules
  - Analytical methods
  - Standardized procedures (e.g., EPA, standard methods) for:
    - BOD/COD
    - TSS
    - Turbidity
    - pH
    - Nutrients (e.g., ammonia, nitrate, phosphate)
    - Pathogen indicators (e.g., E. coli total coliforms)
    - Disinfection residuals (e.g., chloring, UV dose)

Understand common laboratory report elements

- Operators should be familiar with the following components of lab reports:
  - Sample identification: includes date/time, location, and sample type

- Analytical results: reported in appropriate units (e.g., mg/L, NTU, CFU/100mL)
    - Method used: specifies the analytical technique (e.g., SM 2540D for TSS)
    - Detection limits: indicate the sensitivity of the method and whether results are below detection
    - Quality control data: includes blanks, duplicates, and calibration checks
    - Interpretation notes: may consist of comments from lab analysts or automated flags for out-of-range values

Use lab reports for operational decision-making

- Operators should use lab data to:
    - Track trends: identify gradual changes in water quality that may indicate system degradation
    - Diagnose issues
    - Pinpoint problems such as:
        - High TSS indicating poor filtration
        - Low disinfection residuals, suggesting UV lamp failure

Optimize performance

- Adjust operational parameters based on data (e.g., aeration rate, chemical dosing)

Ensure compliance

- Verify that effluent meets reuse standards (e.g., NSF/ANSI 350, local codes)

Implement best practices for operators

- Maintain a logbook or digital record of all lab reports
- Review reports promptly and escalate anomalies
- Understand chain of custody procedures for regulatory samples
- Coordinate with certified laboratories for external testing
- Stay updated on local and national water reuse regulations [SME (RP) input]

9.6.1 Understand different units of measure

The following are quantity/SI units/USCS units of measurement that an operator should know:

- Length/Meter (m)/Feet (ft)
- Mass/Kilogram (kg)/Pound (Ib)
- Temperature/Celsius (C)/Fahrenheit (F)
- Area/Square meter (m^2)/Square foot (ft^2)
- Volume/Cubic meter (m^3)/Cubic foot (ft^3)
- Energy/Kilojoule (kJ)/British thermal unit (Btu)
- Power/Watt (W)/BTU/hr
- Velocity/Meters/Second (m/sec)/Miles/Hour (mph) [Water.mecc.edu p1 Table]

Additional units of measure include:

- Nephelometric Turbidity Unit: NTU
- Milligram per liter: mg/L
- Gram per kilogram: g/Kg
- Gram per liter: g/L
- Standard units: SU
- Most probable number: MPN / 100 mL
- Gallons per day: GPD
- Million gallons per day: MGD
- Cubic meters per day: CMD
- Parts per million: PPM
- Parts per billion: PPB
- Pressure units (PSI, atmosphere, bar, mbar) [SME (TR) input]

9.6.2 Formula Sheet

See Appendix 1.

The San Francisco Museum of Modern Art, which has a rainwater harvesting system [Photo credit: Snohetta]

Test Your Knowledge

Section 9 - Monitoring Water Quality and Physical Parameters

1. What does a grab sample tell the operator?
   A. An average representation of grab samples taken at different times or locations and pooled together to create one sample
   B. An average representation of all water quality exceedances
   C. A water level measurement using ultrasonic waves
   D. A snapshot of the quality of the water at the exact time and place where the sample was taken
2. What is a sample hold time?
   A. A process for maintaining accurate and reliable readings in continuous monitoring instruments
   B. The length of time allowed between when a sample is collected and when it is analyzed
   C. A method of detecting microbial contamination
   D. A measure of water clarity
3. What are examples of common sensors used for continuous monitoring in ONWS? (Select all that apply.)
   A. Chlorine residual meter
   B. Turbidimeter
   C. Online pH meter
   D. Flow meter
4. How do UV intensity sensors work?
   A. Measure the intensity of UV light within the reactor, which can be used to adjust the UV dose in real time
   B. Measure the clarity of the water using a turbidimeter
   C. Measure using monitoring sensors to ensure sufficient aeration for the microbes to consume the biochemical oxygen demand
   D. Monitor the percentage of UV light that passes through a water sample, indicating how clear the water is and assessing the efficiency of UV disinfection
5. Using biological treatment in graywater and blackwater systems helps to reduce BOD, thereby providing the following benefits (Select all that apply.):
   A. Improves the performance of downstream filtration systems
   B. Decreases the risk of sedimentation in storage tanks and distribution systems
   C. Provides a cost-effective way to measure bacterial growth
   D. Results in clearer water with fewer visible particles, enhancing the overall water quality for non-potable applications

Test Your Knowledge (continued)

6. Calculating Wasting Rates
   An ONWS uses an MBR to treat wastewater. The system contains 140 lbs of MLSS in the aeration tank. The operator wants to maintain a Solids Retention Time (SRT) of 15 days.

Using the formula provided below, what is the required daily wasting rate?

A. 6.5 lbs/day

B. 8.0 lbs/day

C. 9.3 lbs/day

D. 10.5 lbs/day

Using the formula:

Wasting Rate (lbs/day) = $\frac{\text{Total MLSS (Lbs)}}{Target\ SRT\ (days)}$

7. Calculating F/M Ratio

A small onsite water reuse system treats **30,000 gallons per day (GPD)** of wastewater. The **influent CBOD concentration** is **10 mg/L**.

The **aeration tank volume** is **15,000 gallons**, and the **MLVSS concentration** is **3,800 mg/L**. Using the formula provided below, what is the F/M Ratio?

A. 0.12

B. 0.07

C. 0.24

D. 0.31

Using the formula:

- F (Food) = Flow (MGD) × CBOD × 8.34
- M (Microorganisms) = Aeration Volume (MG) × MLVSS × 8.34
- F/M Ratio = F ÷ M

8. **Calculating Solids Retention Time (SRT)**
   A small water reuse facility has 100 lbs of MLVSS in its aeration system. The system wastes 8 lbs of MLSS per day. Using the formula provided below, what is the Solids Retention Time (SRT)?

A. 10.3 days

B. 12.5 days

C. 15.9 days

D. 18.0 days

Using the formula:

SRT (days)= $\frac{\text{Total MLSS (lbs)}}{\text{MLSS Wasted lbs/Day}}$

The circulating playground water feature "Amaoto No Komichi" [Photo credit: www.city.hiroshima.lg.jp/site/gesuido/2638.html; Onsite Water Reuse System Innovation Projects San Francisco Public Utilities Commission 2021]

Section 10
Chemical Storage, Handling, and Feeding

10.1 Safe storage, handling, and feeding practices

The section below discusses how to safely store and handle chemicals that are commonly used in ONWS. Additional safety considerations can be found in Section 14.

10.1.1 Design parameters

A safe, effective, and low-maintenance chemical system depends on the size of the storage vessel; the compatibility of the materials with the chemicals; the isolation of the chemical from other incompatible chemicals; and the design of the dosing equipment, piping, and application point. Here, we will focus on sizing and material compatibility. [WWTF 2 Ch10 p5 para1]

10.1.2 Sizing

When determining the appropriate size of a chemical handling system, it is essential to consider the sequence of steps that lead to actually dosing a chemical. Chemical suppliers typically offer standard quantities that can be delivered. In addition, the following questions should be addressed:

- What is the expected average feed rate?
- What is the standard delivery?
- What is the typical lead time for delivery?
- What is the shelf life of the chemical, and how severe is the degradation?
- What is the consequence of running out of a chemical?

The general rule for sizing storage facilities is to provide 1.5 times the volume of the largest expected delivery and sufficient capacity for two weeks of operation to protect against interruptions in the manufacture and transportation of the chemical. [WWTF 2 Ch10 p5 para1-2, p6 para4 + bullets, para5]

10.1.3 Material compatibility

Chemicals are supposed to initiate reactions, and they do so not only in the process but also with everything they come into contact with. Highly inert materials (e.g., plastics, rubber, steel) are resistant to the reaction but not immune to it. As a result, it is essential to select construction materials that are resistant to specific chemicals. Chemicals are corrosive in the same way as the reactions they produce (e.g., acids, bases, oxidizers, reductants); therefore, compatible materials are chosen to minimize maintenance, considering that the cost of the material is typically proportional to its resistance and range of applications. [WWTF 2 Ch10 p6 para5, p7 para1]

Direct contact materials used in the storage and conveyance of chemicals are broken down into two types:

- Hard goods
  - Rigid components of the system (e.g., feeders and pumps, tanks and piping)
  - Metallic components include specialized metal alloys that are chemically resistant
- Soft goods
  - Pliable materials that form seals and flex to pump or meter chemicals
  - Known as elastomers (e.g., gaskets, O-rings, diaphragms, tubing, valve seats) [WWTF 2 Ch10 p7 para2,3]

10.1.4 Equipment

An ONWS needs to store, handle, and dose chemicals, and these tasks require equipment. In general, when chemicals are stored and handled, and people may be exposed, standard equipment must be utilized, including spill containment, chemical sumps and pumps, as well as emergency shower and eyewash stations. [WWTF 2 Ch10 p8 para1]

10.1.4.1 Spill containment

All chemical storage areas must be equipped to handle a catastrophic spill of the entire storage volume. Typically, the containment area should have a volume of 1.1 times (110%) of the full volume of the storage vessel. [WWTF 2 Ch10 p8 para2]

10.1.4.2 Chemical sump and pump

For safety reasons, chemical spills need to be contained. In addition to safety, there are two other reasons that an ONWS needs to be set up to handle a chemical spill. If a large chemical spill is allowed to return directly to the treatment process, it may cause a severe process upset. Chemicals are also expensive, and if it is possible to recover the chemical, it is financially smart to do so. Due to these reasons, containment areas should be equipped with a sump and a pump. [WWTF 2 Ch10 p9 para5]

The sump and the pump handle the chemical, or a diluted version of the chemical, as the containment area is washed down, and both require chemical resistance. The sump should be equipped with a float system that alarms on high level and stops the pump on low level, but it should not start the pump automatically. The pump should only be operated manually to ensure the discharge can be controlled. This setup allows the operator to assess the situation and determine if the chemical is recoverable. [WWTF 2 Ch10 p9 para6, p10 para1,2]

The pump discharge must include valves and piping that facilitate the easy recovery of the spilled chemical. A non-potable facility water line can be piped directly to the sump, allowing for a chemical spill to be diluted as it is pumped to drain and refill the sump with water. This process enables checking the operation of the floats and alarms, as well as exercising the pump. [WWTF 2 Ch10 p10 para2]

10.1.4.3 Emergency shower and eye wash

FIGURE 10.1: *Example of an eyewash station [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

An emergency shower and eye wash station are required in chemical areas in the U.S. by U.S. Occupational Safety and Health Administration (OSHA) regulation 191.151(C). Additionally, the American National Standards Institute has guidance on the design, installation, and operation of emergency shower and eyewash stations in part Z358.1-2014. [WWTF 2 Ch10 p10 para3]

The shower and station can be permanent or portable, but all systems must activate with a stay-open valve and deliver flow in one second or less. Supplementary eyewash bottles can be used in conjunction with permanent or portable eyewash systems, but they should not be used as a substitute for these systems. [WWTF 2 Ch10 p10 para4, p11 para2]

There are flow, pressure, and duration standards for systems designed to flush the eyes only and the eyes and face, and showers to flush the whole body:

- The flushing water must be tepid [60 to 100°F (16 to 38°C)] as this temperature allows a worker to flush themselves for a full 15 minutes comfortably.
- Shower and eyewash stations should be accessible within 10 seconds, as an immediate response to chemical exposure is vital.
- The station must be located on the same level as the hazard – no stairs or other obstructions.
- The shower head should be located no closer than 82 inches from the floor and provide a 20-inch diameter spray at 60 inches from the floor; the center of the spray pattern at that location should have a 16-inch clearance from any obstruction.
- Eyewash stations should be positioned 33 to 53 inches from the floor, with a clearance of 6 inches from any obstruction. [WWTF 2 Ch10 p10 para4, p11 para1+bullets]

Emergency showers and eyewash stations can be equipped with alarms to notify other operators that a station has been activated. [WWTF 2 Ch10 p11 para3]

10.1.5 Receiving facilities

10.1.5.1 Equipment

Chemical receiving operations involve the delivery of the chemical, the off-loading of the chemical, and the vehicle exiting the site, and the entire process needs to be considered, including:

- Where the truck park
- The route of the flexible hoses
- Pipe connections
- Mechanical equipment (e.g., blowers, compressors, pumps)
- Various safety and spill containment provisions

The chemical can be transferred to the storage tank in different ways. The easiest way to complete the transfer is by gravity if the tanks are located below grade. The truck can also be pressurized with compressed air, which displaces the chemical, or it can be connected to a transfer pump, and the chemical is pumped into the tank. Some dry chemicals (e.g., lime, dry polymers) can be transferred using air blowers. [WWTF 2 Ch10 p15 para1, p16 para1]

10.1.5.2 Operations

Physical and operational safeguards should be implemented to prevent the chemical from being offloaded into the wrong storage tank. At a minimum, the fill connections should be clearly labeled. Typically, the connections can be locked with unique locks for each chemical. The operations staff should be aware of the chemical delivery schedule, and the chemical supplier/shipper should be able to contact the facility staff upon arrival. [WWTF 2 Ch10 p16 para2]

10.1.5.3 Maintenance

Mechanical equipment should be maintained according to the manufacturer's recommendations. Fill pipes and connections (e.g., gaskets, grooves, cam arms) must be monitored for leaks, and any leaks must be repaired immediately. If they cannot be sealed as intended, they should be replaced immediately. The chemical sump and pump should be tested regularly and not allowed to sit full of chemicals. Finally, the emergency shower and eyewash station should also be tested regularly to ensure the supply pipes have fresh water and verify that the alarm systems are functioning properly. [WWTF 2 Ch10 p16 para3]

10.1.6 Transfer

Depending on the size of the system, the chemical may be dosed directly from the bulk storage tank or distributed to day tanks. A day tank is a smaller tank that is filled from the bulk tank several times a day to once every few days. Day tanks have the same features as bulk tanks. The level in the day tank is monitored remotely, and the tank is automatically filled based on preset start and stop levels. The level triggers the transfer pump to start and fill the tank, while the stop level shuts off the pump. Automated fill valves are typically included at the bulk tank and the day tank. This allows a single transfer pump to fill different day tanks. [WWTF 2 Ch10 p17 para1, p18 para1]

10.1.6.1 Equipment

There are different pieces of equipment to be utilized in chemical storage, handling, and feeding, including:

Chemical transfer pumps are designed to move a large volume of chemical in a short amount of time and do not need variable speed to control the dose.

- Diaphragm pumps are suitable for smaller volume transfers.
- Centrifugal transfer pumps can move a much larger liquid volume than diaphragm pumps.
- Centrifugal chemical pumps can be designed with magnetic drives that eliminate shaft penetration, allowing the pump volute to be totally enclosed and minimizing the potential for leaks.
- Positive displacement pumps are also used for chemical transfer, particularly for viscous chemicals such as polymers or slurries, including magnesium hydroxide or lime solutions.
- Progressing cavity pumps or rotary lobe pumps are commonly used for viscous chemicals.
- Automated isolation valves are used in chemical transfer systems to control which tank is being used for supply and which tank is being filled.
- Remote level indication is necessary to transfer operation to prevent overfilling the day tank or running the tank and dosing pump dry. [WWTF 2 Ch10 p18 para1-6, p19 para1-2]

10.1.6.2 Operation

Chemical transfers can be operated in automatic, semiautomatic, or manual modes. An automatic chemical transfer sequence is initiated by the low-level setpoint in the day tank. Semiautomatic operation should be used primarily to periodically monitor the transfer sequence. In manual mode, the operator is responsible for operating each piece of equipment in the system and must follow the proper sequence to complete the transfer. Manual mode is used in the event of a loss of controls, to prevent an automatic transfer, or to control the volume of chemical transferred. [WWTF 2 Ch10 p19 para3]

10.1.6.3 Maintenance

Chemical transfer pumps and automatic actuated isolation valves need to be maintained according to the manufacturer's recommendations. Pump maintenance involves replacing diaphragms, O-rings, check valves, and other seals that come into contact with the chemical. These items should be kept in stock for emergency repairs. If the system includes strainers or screens on the chemical supply, they need to be cleaned on a regular schedule. If leaks occur in the chemical transfer system, they need to be addressed immediately. All connectors, couplings, and joints should be inspected for leaks on a regular schedule. [WWTF 2 Ch10 p20 para2-3]

10.1.7 Dry chemical systems

A dry chemical system starts with a storage container that supplies the dry chemical to a feeder. The feeder is the metering component of the system, controlling the dose of the chemical. The metered chemical is either fed directly into a solution tank or directed to a solution tank and then to the application point. [WWTF 2 Ch10 p22 para1]

10.1.8 Liquid chemical systems

A liquid chemical system is similar to a dry chemical system. The system starts with a storage tank that holds the chemical for dosing to a dry tank. The chemical is dosed with a chemical metering pump, either directly to the application point or into a pipe with carrier water flowing to the application point. At the application point, the chemical is mixed with the process water. [WWTF 2 Ch10 p30 para1]

FIGURE 10.2: *Blue tanks store liquid chemicals for use in an ONWS [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

10.1.9 Chemical application

The application point is the location where the chemical is first introduced into the process stream, and the reaction begins. For the reaction to occur, the reactants must come into contact with each other, so some mixing energy must be applied at the point of application. The application point must also be located to give sufficient detention time in the process for the reaction to proceed to completion. Chemicals may be applied to processes in various locations, but are typically separated into open-channel applications or in-pipe applications. [WWTF 2 Ch10 p43 para1-2]

10.2 Dosage calculation (flow rate, stock chemical concentration, target chemical concentration)

All formulas supporting the guidance in this section are provided in the Formula Sheet in the Appendix and should be referenced as needed.

10.2.1 Flow rate

Flow rate is the volume of water being treated per unit of time. It is typically expressed in gallons per minute or liters per second, but can be converted to other units to calculate dosages for a desired concentration of chemical.

10.2.2 Stock chemical concentration

Process:

1. Determine the desired dose: Identify the target concentration of the chemical in the treated water (mg/L).
2. Calculate the required volume: Determine the volume of water to be treated (in liters or gallons).
3. Prepare stock solution: Mix the chemical with water to create a stock solution of known concentration (mg/L or % w/v).
4. Dilution: Dilute the stock solution to achieve the desired dose in the treatment system.

Formula:

$$\textbf{Stock Solution Concentration (mg/L)} = \frac{\textbf{Desired Dose}\left(\frac{\textbf{mg}}{\textbf{L}}\right)\times \textbf{Volume of Treated Water (L)}}{\textbf{Volume of Stock Solution (L)}}$$

Example Calculation: If you need to dose 10 mg/L of a chemical into 1,000 liters of water using a 1-liter stock solution, the stock solution concentration would be:

$$\textbf{Stock Solution Concentration (mg/L)} = \frac{\textbf{10}\left(\frac{\textbf{mg}}{\textbf{L}}\right)\times \textbf{1,000 (L)}}{\textbf{1 (L)}} = \textbf{10,000 mg/l}$$

10.2.3 Target chemical concentration

10.2.3.1 Overview

Target chemical concentration refers to the desired level of a specific chemical or parameter in the treated water that achieves effective treatment and ensures safe reuse. It is crucial for maintaining water quality and meeting regulatory standards.

10.2.3.2 Process

1. Determine desired outcome: Identify the specific treatment goals, such as disinfection, nutrient removal, or pH adjustment.
2. Calculate dose: Use the target concentration to calculate the required dose of chemicals or treatment agents.
3. Monitor and adjust: Continuously monitor the treated water to ensure the target concentration is maintained and make adjustments as needed.

10.2.3.3 Formula

$$\textbf{Target Concentration (mg/L)} = \frac{\textbf{Desired Dose (mg/l)} \times \textbf{Flow Rate (l/min)}}{\textbf{Chemical Concentration (mg/l)}}$$

Here is an example calculation:

If you need to achieve a target concentration of 2 mg/L of chlorine in a water flow of 500 L/min using a stock solution with a concentration of 10,000 mg/L, the required dose would be:

$$\textbf{Target Concentration (mg/L)} = \frac{\mathbf{2\ (mg/l) \times 500\ (l/min)}}{\mathbf{10{,}000\ \ (mg/l)}} = \mathbf{0.1\ l/min}$$

Convert to GPM: 0.1 l/min x 3.785 l/gal = 0.3785 gpm

10.2.4 Chemical dose

Chemical doses are typically expressed in milligrams per liter (mg/L), referring to the amount of active chemical applied per liter of process flow, or in parts per million (ppm). These two units are equivalent and interchangeable with each other. One milligram of a substance per 1 L of water is equivalent to 1 part per million (ppm) because the density of water is 1 g/mL, which means that 1 L of water has a mass of 1,000,000 mg. This can be shown by converting the liter of water to milligrams of water using the density:

1L (1g/mL) (1000mL/1 L) (1000mg/1 g) = 1,000,000 mg

A dose of 1 mg/L means that 1 mg of active chemical is present for every 1 million mg of water. [WWTF 2 Ch10 p51 para1, p52 para1]

10.2.5 Chemical dose and feed rate calculations

The dose and feed rate can be calculated in both directions, and the operator should understand both. Typically, a desired dose is determined for a chemical system, and the feed rate is calculated to set the output of the chemical feeder or to check the output of the chemical pump with the calibration column. If the chemical feeder is delivering a constant flow, the calculation is reversed to determine the applied dose. Note that the dose always refers to the active chemical, and the feed rate refers to the volume or mass of neat chemical delivered. [WWTF 2 Ch10 p52 para2]

10.2.5.1 Chemical feed rate/dose formula

Chlorine Feed Rate (lbs/day)

To calculate the amount of chlorine needed to treat water:

Chlorine lbs/day = Dose (mg/L) × Flow (MGD) × 8.34

- mg/L = desired chlorine dose
- MGD = flow in million gallons per day
- 8.34 = weight of water in lbs/gallon × conversion factor

Example 1:

What is the chlorine feed rate (lbs/day) for a 3 MGD flow with a 4 mg/L dose?

4 × 3 × 8.34 = 100 lbs/day

Example 2:

What is the feed rate for 875,000 GPD (0.875 MGD) with a 2.7 mg/L dose?

2.7 × 0.875 × 8.34 = 19.7 lbs/day

Chlorine Dose (mg/L)

To find the chlorine dose when the feed rate is known:

Dose (mg/L) = lbs/day ÷ (Flow (MGD) × 8.34)

Example 3:

A chlorinator is set to 35 lbs/day. What is the dose for 1.15 MGD?

35 ÷ (1.15 × 8.34) = 3.66 mg/L

Dose = Demand + Residual

Dose (mg/L) = Demand (mg/L) + Residual (mg/L)

Example 4:

If chlorine demand is 1.9 mg/L and desired residual is 0.8 mg/L:

1.9 + 0.8 = 2.7 mg/L dose

ADVANCED

10.3 Under-/Over-dosing

Operators must manage the chemical makeup of wastewater to keep effluent within permit parameters and maintain safety. Accurate measurement of both the water and the chemicals being added is crucial. Operators must also understand how wastewater constituents react when chemicals are introduced. Understanding the interactions between different chemicals and wastewater constituents is essential. For example, the pH level can significantly affect the efficacy of certain chemicals.

10.3.1 Under-dosing

Under-dosing occurs when insufficient chemicals are added to keep wastewater within regulatory limits. This can lead to fines and operational mandates. For example, if the chemical dosage is too low, contaminants may not be adequately neutralized, resulting in noncompliant effluent. Implementing real-time monitoring systems can help operators adjust chemical dosages dynamically, ensuring optimal treatment and compliance with regulatory standards.

10.3.2 Over-dosing

Over-dosing involves adding too much of a chemical, which can cause balance issues. For instance, excessive use of polymer during flocculation can create floc that is too small and light, causing it to float rather than settle. This floating floc, containing contaminants, can lead to effluent that fails to meet permit standards. Utilizing automated dosing systems can enhance accuracy and consistency in chemical addition, reducing the risk of under- or over-dosing.

10.3.3 Advanced Considerations

- Chemical interactions: Understanding the interactions between different chemicals and wastewater constituents is essential. For example, the pH level can significantly affect the efficacy of certain chemicals.
- Real-time monitoring: Implementing real-time monitoring systems can help operators adjust chemical dosages dynamically, ensuring optimal treatment and compliance with regulatory standards.
- Automated dosing systems: Utilizing automated dosing systems can enhance accuracy and consistency in chemical addition, reducing the risk of under- or over-dosing.
- Training and education: Continuous training for operators on the latest technologies and best practices in chemical dosing can improve system performance and compliance.
- Case studies and best practices: Reviewing case studies and best practices from other facilities can provide valuable insights into effective dosing strategies and common pitfalls to avoid.

By focusing on these advanced considerations, operators can better manage the chemical dosing in onsite water reuse treatment systems, ensuring both regulatory compliance and operational efficiency.

Plaza outside of a subway station that is collecting foundation drainage for reuse in a nearby steam heating plant in San Francisco, CA [Photo credit: San Francisco Public Utilities Commission. Permission to use.]

Test Your Knowledge

Section 10 - Chemical Storage, Handling, and Feeding

1. What is the rule of thumb for sizing chemical storage?
   A. Provide enough for six months of operation
   B. Provide enough for three times the volume of the largest expected delivery and enough for one month of operation
   C. Provide 1.5 times the volume of the largest expected delivery and enough for two weeks of operation
   D. Provide enough for three months of operation
2. When chemicals are stored and handled onsite and where an operator may be exposed, what safety measures should be in place? (Select all that apply.)
   A. Presence of an aerator
   B. Spill containment
   C. Chemical sumps and pumps
   D. Emergency shower and eye wash stations
3. True or False. Shower and eyewash stations should be reachable within 10 seconds because immediate response to chemical exposure is vital.
   A. True
   B. False
4. Under-dosing of chemicals can lead to what issue?
   A. Pathogens may not be adequately inactivated or destroyed
   B. Pump failure
   C. Reduced UV Transmittance
   D. Increased confidence in system operability
5. Because an accurate measurement of chemicals being added is crucial, what is one strategy an operator can use to prevent under- or overdosing?
   A. Use the critical control point framework to reduce and prevent hazards
   B. Utilize automated dosing systems can enhance accuracy and consistency in chemical addition
   C. Establish diversion setpoints to redirect flow to the sewer
   D. Perform a challenge test with an appropriate surrogate parameter

Test Your Knowledge (continued)

6. Calculating Stock Concentration

A small water reuse system operator needs to achieve a **chlorine dose of 0.5mg/L in 15,000 liters of treated water**. The available disinfectant is **12.5% sodium hypochlorite** (which is **125,000 mg/L as a stock solution**).

Using the formula provided below, how many liters and gallons of 12.5% hypochlorite are needed (1 gallon = 3.785 liters)?

A. 0.15 L (0.57 gal)

B. 0.06 L (0.23 gal) (Correct Answer)

C. 0.75 L (0.20 gal)

D. 1.00 L (0.26 gal)

Using the formula:

Volume of Stock Solution (L) = $\dfrac{Desired\ Dose\ \left(\frac{mg}{l}\right)\ x\ Volume\ of\ Water\ (l)}{\text{Stock Solution concentration}\ (\frac{\text{mg}}{\text{l}})}$

(1 gallon = 3.785 liters)

7. Calculating Chemical Dose and Feed Rate

A water reuse system operator needs to dose 0.6 mg/L of chlorine into a flow of 0.25 MGD using a 12.5% sodium hypochlorite solution (which is 125,000 mg/L).

Using the formula provided below, what is the required chemical feed rate?

A. 3.78 L/day

B. 5.67 L/day

C. 4.54 L/day

D. 9.46 L/day

Using the formula:

Chemical Feed Rate (L/day) = $\dfrac{\text{Desired Dose}\ \left(\frac{\text{mg}}{\text{l}}\right) x\ Flow\ Rate\ (MGD) x\ 3.785\ x\ 10^6}{2aChemical\ concentratiuon\ (\frac{mg}{l})}$

Mazda Stadium in Hiroshima, Japan, that uses rainwater for irrigation [Photo credit: City of Hiroshima]

Section 11
Process Control and Online Monitoring

Supervisory control and data acquisition (SCADA) systems are a crucial tool for the effective and efficient monitoring and control of wastewater. [WWTF 3 Ch13 p1 para1]

11.1 Introduction

11.1.1 Why

Process control is vital for protecting public health, meeting all necessary regulatory requirements, and for the practical monitoring and operation of an ONWS. [2024 WPI Onsite Non-potable ECO Exam Specifications Outline]

11.1.2 How

Process control is managed through critical operational parameters, SCADA, telemetry, and online instruments (i.e., computer interfaces and monitoring). [2024 WPI Onsite Non-potable ECO Exam Specifications Outline]

11.2 Critical control point framework

The critical control point framework consists of vital parameters that, if not met, cause the system to shut down or divert to drain. [SME (TR) input]

Critical control points (CCPs) are specific points in the treatment process that are designed to reduce, prevent, or eliminate a human health hazard, and for which controls exist to ensure the proper performance of that process. [Hazen and Sawyer Critical Control Point 2020 p11 sidebar] Some fundamental questions should be asked to identify CCPs:

- Is there a hazard at this step?
- Can this step control it in the process train?
- Is this step intended to eliminate or reduce the risk?

[Hazen and Sawyer Critical Control Point 2020 p15]

The critical control point framework relies strictly on treatment process performance monitoring, eliminating the need for effluent monitoring. [NBRC ONWS Guidance Manual p64]

CCPs (also referred to as critical control points) dictate when automatic diversion to sewer would be required. For example, California's proposed regulations for ONWS include prescribed limits for pathogen control treatment trains (see example below). For other non-prescribed, alternative treatment trains, CCPs can be established based on field verification. [State Water Resources Control Board, 2022 slide32]

Pathogen Control Treatment Train	Treatment Process	Critical Control Limits*
Train A: MBR – UV – Free Cl2	MBR	Turbidity <0.2 NTU 95% of the time within 24 hrs, <0.5 NTU at any time
	UV	Dose >160 mJ/cm²
	Free Cl2	CT>12 mg-min/L
Train B: MBR – UV – Free Cl2	MBR	Turbidity <0.2 NTU 95% of the time within 24 hrs, 0.5 NTU at any time
	UV	Dose >120 mJ/cm²
	Free Cl2	CT >16 mg-min/L
Train C: MBR – UV – Free Cl2	MBR	Turbidity <0.2 NTU 95% of the time within 24 hrs, 0.5 NTU at any time
	UV	Dose >160 mJ/cm²
	Free Cl2	CT >7 mg-min/L
Train D: MBR – UV	MBR	Turbidity <0.2 NTU 95% of the time within 24 hrs, 0.5 NTU at any time
	UV	Dose >240 mJ/cm²
Train #: Membrane filtration – UV – Free Cl2	Membrane filtration	Turbidity <0.2 NTU 95% of the time within 24 hrs, 0.5 NTU at any time
	UV	Dose >160 mJ/cm²
	Free Cl2	CT >10 mg-min/L
Train F: UV	UV	Dose >40 mJ/cm²

TABLE 11.1: *Proposed Critical Control Limits for Pathogen Control Treatment Trains A-F [California Water Boards Updated OTNWS Treatment Trains Draft Criteria March 2024 Slides 4,5]*

The purpose of field verification at CCPs is to ensure that the unit process is achieving LRTs, and that operational monitoring and control systems are functioning properly. Typically, field verification occurs during commissioning, which encompasses all activities related to bringing a system into service. If required by local and or state regulations, the commissioning plan would include a detailed account of all activities associated with initial process operation through the completion of field verification studies. Field verification studies are conducted after the steady state of the process has been achieved, which can require several weeks for biological processes. The field verification of LRVs typically involves a challenge test using an appropriate surrogate. Indicators for steady-state operation will be defined in the commissioning plan. [Risk-based framework for DNW Systems p 54-55] Operators in other states should consult with their local and state regulators.

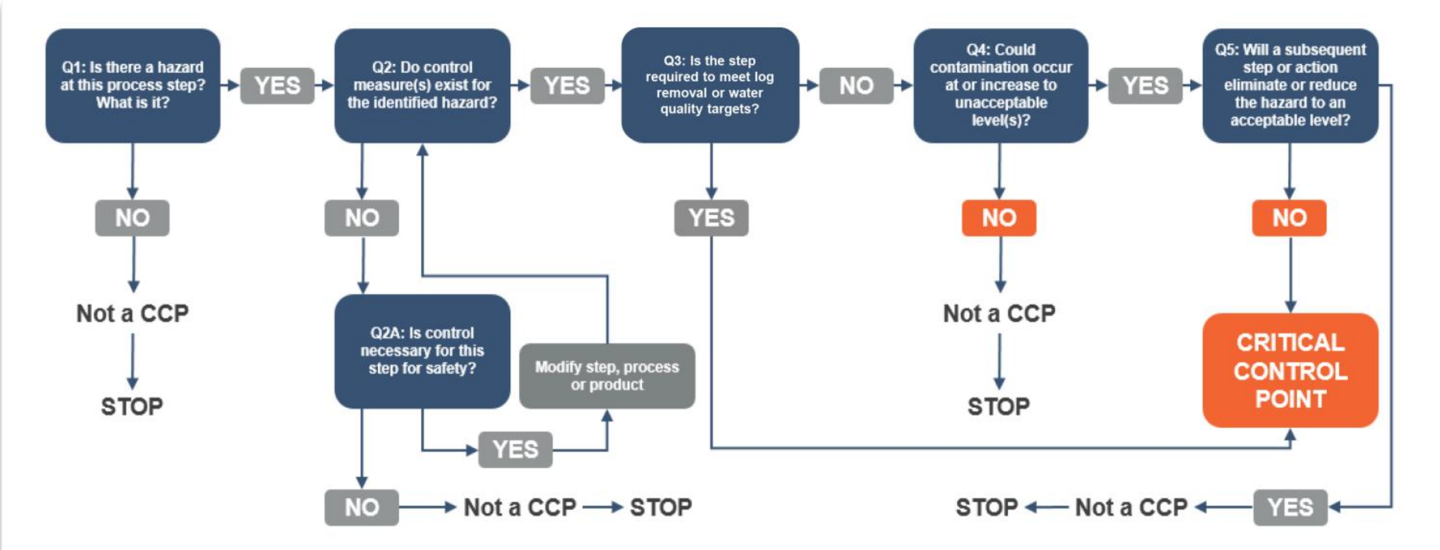


FIGURE 11.1: *Decision tree for determining CCPs. [Hazen and Sawyer Critical Control Point 2020 p15 Graphic]*

11.3 Critical operation parameters for process control

Effective process control and online monitoring are essential for the successful operation of ONWS. These systems require continuous oversight to ensure that water quality meets regulatory standards and that the treatment processes are functioning optimally. The following critical operation parameters should be monitored and controlled:

- Flow rate
  - Instruments: flow meters (e.g., electromagnetic, ultrasonic, or turbine flow meters)
  - Purpose: measure the rate of water flow into and out of the treatment system
  - Setpoints: establish setpoints for the minimum and maximum flow rates based on the system's design capacity
  - Online monitoring: use flow meters to measure inflow and outflow rates continuously; implement alarms for deviations from setpoints to detect anomalies such as leaks or blockages
- pH Levels
  - Instruments: pH sensors and analyzers
  - Purpose: monitor the acidity or alkalinity of the water, which affects chemical treatment processes
  - Setpoints: maintain pH levels within the optimal range for specific treatment processes, typically between 6.5 and 8.5
  - Online monitoring: use pH sensors to monitor pH levels continuously; automated dosing systems can adjust chemical addition to maintain pH within setpoints
- Turbidity
  - Instruments: turbidity meters
  - Purpose: measure the clarity of the water, indicating the presence of suspended solids
  - Setpoints: set turbidity thresholds based on regulatory standards and treatment process requirements
  - Online monitoring: use turbidity meters to monitor water clarity; implement filtration or sedimentation processes to reduce turbidity if it exceeds setpoints

- Dissolved Oxygen (DO)
    - Instruments: DO sensors
    - Purpose: monitor oxygen levels, crucial for biological treatment processes
    - Setpoints: Maintain DO levels within the optimal range for biological treatment processes, typically between 2 and 4 mg/L
    - Online monitoring: use DO sensors to monitor oxygen levels continuously; adjust aeration rates to maintain DO within setpoints
- Chemical dosing
    - Instruments: automated dosing systems with real-time monitoring
    - Purpose: ensure accurate and consistent chemical addition for effective treatment
    - Setpoints: establish setpoints for chemical dosages based on treatment requirements and regulatory limits
    - Online monitoring: implement automated dosing systems with real-time monitoring to ensure accurate chemical addition; regularly calibrate dosing equipment to maintain precision
- Temperature
    - Instruments: temperature sensors
    - Purpose: monitor water temperature, which affects chemical reactions and biological processes
    - Setpoints: maintain temperature within the optimal range for chemical reactions and biological processes, typically between 15°C and 35°C
    - Online monitoring: use temperature sensors to monitor water temperature continuously; adjust heating or cooling systems as necessary to maintain setpoints

11.4 Automated responses (diversion, shutdowns, alarms)

Automated responses are crucial for maintaining the efficiency and safety of ONWS. These responses include diversions, shutdowns, and alarms, which help operators manage the system effectively and respond promptly to any issues.

11.4.1 Diversion

- Diversion mechanisms are used to redirect water flow when certain conditions are met, ensuring that the system continues to operate within safe and optimal parameters.
- Setpoints: Diversion setpoints are established based on parameters such as turbidity, pH, and flow rate. For example, if turbidity exceeds a certain threshold, the system can automatically divert water to a holding tank for further treatment.
- Online monitoring: Continuous monitoring of water quality parameters allows the system to detect when diversion is necessary. Sensors and analyzers provide real-time data, enabling immediate action.

11.4.2 Shutdowns

Shutdowns are automated responses that halt system operations to prevent damage or ensure safety when critical parameters are outside of their normal range.

- Setpoints: Shutdown setpoints are defined for critical parameters such as high turbidity, low dissolved oxygen, or extreme pH levels. For instance, if pH levels fall outside the acceptable range, the system can automatically shut down to prevent damage to equipment or ensure compliance with regulatory standards.
- Online monitoring: Real-time monitoring systems continuously track critical parameters. When a parameter exceeds its setpoint, the system triggers an automatic shutdown to protect the integrity of the treatment process.

11.4.3 Alarms

Alarms alert operators to potential issues, allowing for timely intervention before problems escalate.

- Setpoints: Alarm setpoints are established for various parameters, including flow rate, chemical dosing, and microbial activity. For example, an alarm can be set to trigger if the flow rate drops below a certain level, indicating a potential blockage or leak.
- Online monitoring: Sensors and analyzers continuously monitor system parameters. When a parameter deviates from its setpoint, the system triggers an alarm, notifying operators of the issue. Alarms can be visual, auditory, or sent as notifications to operators' devices.

11.4.4 Integration of automated responses

- Real-time data acquisition: Continuous data collection from sensors and analyzers allows for immediate detection of deviations from setpoints.
- Automated control systems: Integration of automated control systems with online monitoring ensures that adjustments to the treatment process are made in real time, enhancing system reliability and performance.
- Data logging and reporting: Maintaining a comprehensive log of operational data enables the tracking of system performance over time and the identification of trends or recurring issues.
- Alarm and notification systems: Setting up alarms for critical parameters ensures that operators are immediately alerted to potential problems, allowing for swift corrective actions. Operators should be on-call to receive notifications and alarms after working hours.

By implementing these automated responses, operators can ensure the effective and efficient operation of ONWS, maintaining compliance with regulatory standards and optimizing overall system performance.

11.5 Elements of process control systems

11.5.1 SCADA and telemetry

Operators require instant access to information that enables them to analyze data on a regular basis. Digital monitoring ensures that the data received is more accurate and up-to-date. Flowmeters are data loggers installed in strategic locations that send data to remote terminal units, which then transmit the collected data to operators. With this information, the operators can see issues such as leaks, overflows, or chemical imbalances. Access to this information allows operators to gain early knowledge, helping them proactively address these issues, which in turn reduces downtime for machinery.

In addition, efficient and accurate automated monitoring is crucial to an ONWS, as some problems (e.g., overflows) that are not addressed promptly can result in EPA regulation violations and fines. SCADA can also help decrease operating costs by allowing operators to identify critical systems that need further optimization and prioritization. [Alliance Water Resources, n/d]

FIGURE 11.2: *Operators use process control systems to access information on the treatment system in real time [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

11.5.2 Process instrumentation systems

Process instrumentation systems are essential for the effective monitoring and control of ONWS. These systems ensure that all critical parameters are continuously measured and maintained within setpoints to achieve optimal performance and regulatory compliance.

11.5.2.1 Integration and automation

- Real-time data acquisition: Continuous data collection from various sensors and analyzers allows for immediate detection of deviations from setpoints.
- Automated control systems: Integration of automated control systems with online monitoring ensures that adjustments to the treatment process are made in real time, enhancing system reliability and performance.
- Data logging and reporting: Maintaining a comprehensive log of operational data enables the tracking of system performance over time and the identification of trends or recurring issues.
- Alarm and notification systems: Setting up alarms for critical parameters ensures that operators are immediately alerted to potential problems, allowing for swift corrective actions.

11.5.3 Instrument calibration to verify treatment performance

Calibration of instrumentation is a critical aspect of ensuring the accuracy and reliability of data collected from ONWS. Proper calibration helps verify that the treatment processes are performing as intended and that the effluent meets regulatory standards.

11.5.3.1 Importance of calibration

- Accuracy: Being accurate ensures instruments provide precise measurements, which are essential for maintaining treatment performance and compliance with regulatory standards.
- Reliability: Regular calibration helps prevent data drift and ensures consistent performance of the treatment system.
- Optimization: Accurate data enables better optimization of treatment processes, resulting in improved efficiency and cost savings.

11.5.3.2 Key instruments for calibration

- Flow meters
    - Calibration Frequency: Typically calibrated annually or as recommended by the manufacturer.
    - Procedure: Use a known volume of water to verify the accuracy of the flow meter readings. Adjust the meter as necessary to match the known volume.
- pH sensors
    - Calibration Frequency: Calibrated monthly or as needed based on usage and manufacturer recommendations.

    - Procedure: Use standard buffer solutions (e.g., pH 4, 7, and 10) to calibrate the sensor. Adjust the sensor readings to match the known pH values of the buffer solutions.
- Turbidity meters
    - Calibration Frequency: Calibrated quarterly or as recommended by the manufacturer.
    - Procedure: Use standard turbidity solutions to verify the accuracy of the meter. Adjust the meter readings to match the known turbidity values.
- DO sensors
    - Calibration Frequency: Calibrated monthly or as needed based on usage and manufacturer recommendations.
    - Procedure: Use a zero-oxygen solution and a saturated oxygen solution to calibrate the sensor. Adjust the sensor readings to match the known oxygen levels.
- Chemical dosing systems
    - Calibration Frequency: Calibrated quarterly or as recommended by the manufacturer.
    - Procedure: Verify the dosing rate by measuring the volume of chemical dispensed over a set period. Adjust the dosing system to match the desired dosing rate.
- Temperature sensors
    - Calibration Frequency: Calibrated annually or as recommended by the manufacturer.
    - Procedure: Use a calibrated thermometer to verify the accuracy of the temperature sensor. Adjust the sensor readings to match the known temperature.

11.5.3.3 Calibration procedures

- Documentation: Maintain detailed records of all calibration activities, including dates, procedures, and any adjustments made.
- Standard Operating Procedures (SOPs): Develop and follow SOPs for calibration to ensure consistency and accuracy.
- Training: Ensure that operators are trained in proper calibration techniques and understand the importance of accurate instrumentation.
- Verification: Periodically verify the performance of calibrated instruments by comparing their readings with known standards or reference instruments.

11.6 Computer skills

11.6.1 Local operator interfaces

Local operator interfaces enable operators to have a clear view of the process, situated near the equipment being controlled. Due to their location, local operator interfaces enable operators to verify proper monitoring and control of necessary actions, such as maintenance or troubleshooting. [WWTF 3 Ch13 p10 para2]

FIGURE 11.3: *Typical local operator interface [WWTF 3 Ch13 p10 Figure13.7]*

11.6.2 Human-machine interface (HMI)

The human-machine interface is a vital part of SCADA because it provides the operator with the ability to monitor and control the facility, as well as collect and store data for reporting and analysis. Core functions include:

- Communication to/from controllers to gain process information and send commands
- Alarm notification, including classification, prioritization, organization, management, and acknowledgment of process alarms
- Displaying process information on graphical displays that also allow operators to send commands or adjust setpoints
- Historical data collection for retrieval, display, and reporting

[WWTF 3 Ch13 p10 para3+bullets, p11 bullets, p19 para1]

In a small facility, the human-machine interface may be provided by a single personal computer. In contrast, in larger facilities, a system of computers will be required, with each one playing a specific role. The collection and storage of data in a SCADA system can be stored in data storage systems with time stamps, providing operators with the ability to track trends and improve reporting. [WWTF 3 Ch13 p11 para1, p19 para1]

FIGURE 11.4: *Example of HMI screen [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

Rainwater cistern *[Photo Credit: San Francisco Water Public Utilities Commission. Permission to use.]*

Test Your Knowledge

Section 11: Process Control and Online Monitoring

1. What is the Critical Control Point (CCP) framework?
    A. A real-time monitoring system to help operators adjust chemical dosages dynamically
    B. A framework of critical parameters that, if not met, causes the system to shut down or divert to drain
    C. A safety plan for preventing chemical leaks and spills
    D. A maintenance plan for maintaining a UV reactor
2. pH sensors and analyzers should be used to monitor and keep pH levels in what range?
    A. 5.5-6.5
    B. 8.5-10
    C. 6.5-8.5
    D. 4.5-5.5
3. What is the appropriate response for an ONWS when critical parameters are out of range?
    A. Keep operating as usual
    B. Spill excessive water on the floor
    C. Shut down all pumps to send water to the toilets
    D. Automated diversion to sewer
4. True or False. Online monitoring and telemetry give operators intermittent access to information that allows them to analyze water quality and system performance data only upon request.
    A. True
    B. False
5. What is the calibration procedure for a DO sensor?
    A. Use a zero-oxygen solution and a saturated oxygen solution to calibrate the sensor, and then adjust the sensor readings to match the known oxygen levels
    B. Use a calibrated thermometer to verify the accuracy of the sensor
    C. Verify the dosing rate by measuring the volume of chemical dispensed over a set period
    D. Use standard turbidity solutions to verify the accuracy of the sensor

San Francisco's MOMA's living wall that is irrigated with treated rainwater *[Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

Section 12
Standard Operating Procedures (SOPs)

12.1 Standard operating procedures

Standard operating procedures (SOPs) are step-by-step instructions developed to help operators execute complex or routine operations of specific equipment. The goal is to achieve efficient and consistent performance while minimizing miscommunication and noncompliance. SOPs, for example, could cover preventative maintenance on a meter that would be included in an operations plan. These procedures are often developed by the operators, who ensure they are aligned with their skill level, with input from the design engineer, system integrator, and equipment manufacturers. SOPs also help ensure that proper knowledge transfer occurs when staff are absent or turnover. Examples of SOPs for an ONWS include, but are not limited to:

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

SOPs should be kept onsite in an easily accessible location and identified for all operators. Electronic versions of the SOPs should also be maintained, so that if any procedures change, the SOPs can be updated and kept current. [NBRC ONWS Guidance Manual p76 para1 + bullets, para2]

SOPs provide consistency for the ONWS, help train new employees and ensure consistent actions by regular staff. They help ensure that all tasks are completed correctly and consistently, regardless of who is performing them. Advantages of SOPs include:

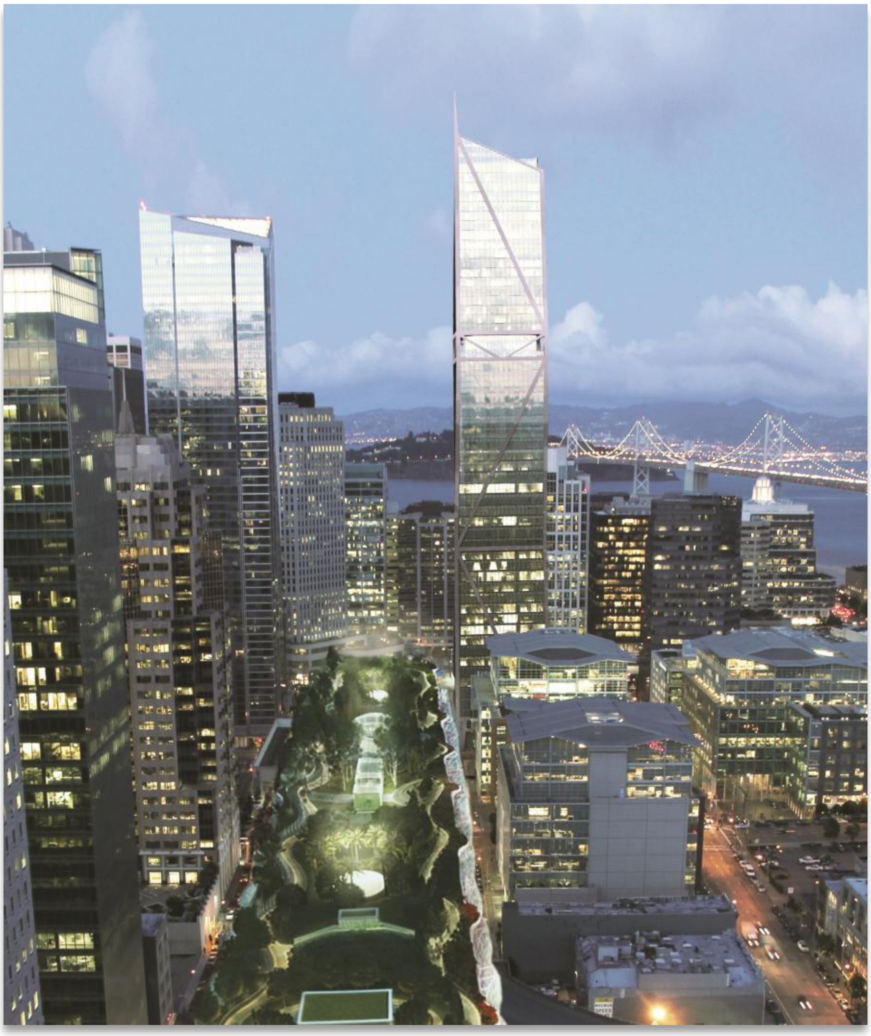
- Promote quality through consistency, even if the staff changes
- Ensure tasks are performed consistently and in compliance with rules
- Help minimize confusion
- Increase safety [WWTF 3 Ch14 p16 para1+bullets]

SOPS need to be maintained to ensure they are current and cover all appropriate activities in an ONWS. Often, this task is addressed by having an SOP library. Typically, changes to SOPs will occur due to process change or operational changes and may include:

- New equipment with special maintenance needs
- Current equipment with changing maintenance needs due to the aging process
- New regulations that require a different approach [WWTF 3 Ch14 p18 para4+bullets, p19 bullets]

Additional safety considerations for operators are covered in Section 14.

FIGURE 12.1: *Operator SOPs should be maintained and followed to ensure consistent actions by staff [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*



The 181 Fremont Mixed-use Tower [Photo credit: Jay Paul Company and Heller Manus Architects]

Test Your Knowledge

Section 12: Standard Operating Procedures (SOPs)

1. True or False. SOPs are the same as the operations plan.
    A. True
    B. False
2. What are standard operating procedures (SOPs)?
    A. Detailed plan for bringing the ONWS into normal working conditions
    B. A list of all confined spaces and classifications based on hazard level
    C. A map showing the locations of all chemical spill kits
    D. Step-by-step instructions were developed to help operators execute complex or routine operations of specific equipment
3. Why are SOPs useful? (Select all that apply.)
    A. Ensure tasks are performed consistently and in compliance with rules
    B. Help minimize confusion
    C. Require operators to work overtime
    D. Increase maintenance responsibilities for the operator
4. SOPs are usually developed by the following members of the ONWS team (Select all that apply.):
    A. Regulator
    B. Building occupants
    C. Operator
    D. Design engineer
5. Changes to SOPs typically occur for which of the following reasons?
    A. New equipment
    B. Maintenance changes
    C. New regulations
    D. All of the above

Roof of the Solair building in NYC, which recycles its blackwater onsite *[Photo credit: Natural Systems Utilities]*

Section 13
Basics of Collection, Distribution, and Storage

13.1 Basics of pumps, valves, and water meters

13.1.1 Pumps

13.1.1.1 Introduction

Pumps are the “workhorses” that make every aspect of water reuse happen. There are many different types of pumps, and they are used to move water, wastewater, chemicals, and solids from one location to another. They are critical tools that help operators reclaim water.

These pumps:

- Move water through the collection system
- Increase the elevation of water in a tank or distribution box so it can flow by gravity to downstream processes.
- Meter chemicals into tanks or processes
- Regulate recycle streams
- Move treated water from the storage tank to end uses (e.g., toilets)

[WWTF 2 Ch7 p2 para1]

In an ONWS, dynamic and positive displacement pumps can work together to efficiently manage water resources. For instance, a centrifugal pump (also known as a dynamic pump) might be used to move treated graywater from a storage tank to various end uses, such as toilet flushing and irrigation. Meanwhile, a diaphragm pump (a type of positive displacement pump) can be used to transfer water from a collection tank to a treatment unit. The diaphragm pump's ability to provide a consistent flow, regardless of pressure, ensures that water is steadily supplied to the treatment unit, where it undergoes the necessary processes before being reused.

13.1.1.2 Types of Pumps

There are several different types of pumps used in an ONWS. **Figure 13.1** shows the most commonly used pumps. Pumps are typically categorized as either kinetic/dynamic or positive displacement.

Kinetic/dynamic pumps

Kinetic/dynamic pumps operate by increasing the velocity of the water and/or solids as they move through the pump and include centrifugal and turbine pumps.

Positive displacement pumps

Positive displacement pumps operate by taking a fixed volume of fluid or sludge from the inlet through the pump body and then pushing it out of the pump discharge and include reciprocating types (diaphragm, piston, and plunger) and rotary types (lobe, progressing cavity, screw, and peristaltic).

Pumps may be submerged in the fluid they are pumping or be placed external to the fluid. Performing maintenance on submerged pumps requires removal from the submerged environment. Care must be taken when putting the pumps back in service to ensure they are level and seated properly for operation.

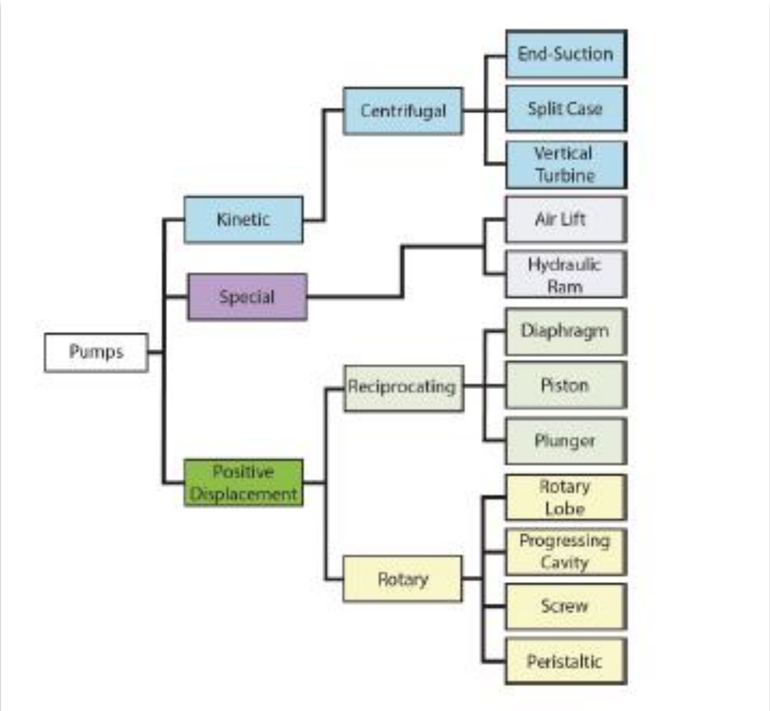


FIGURE 13.1: Common wastewater pump types [WWTF 2 Ch7 p3 Figure7.1]

13.1.1.3 Maintenance procedures for pumps

To ensure the efficient operation of pumps, the following maintenance procedures should be performed regularly:

- Inspecting and cleaning: Regularly inspect the pump for any signs of wear, corrosion, or damage. Clean the pump and its components to remove any debris, dirt, or contaminants that could affect its performance.
- Lubrication: Lubricate the pump's moving parts according to the manufacturer's recommendations. Proper lubrication reduces friction and wear, thereby extending the pump's lifespan.
- Checking seals and gaskets: Inspect the seals and gaskets for signs of wear or leakage. Replace any damaged seals or gaskets to prevent fluid leaks and maintain the integrity of the pump's performance.
- Monitoring vibration and noise: Pay attention to any unusual vibrations or noises coming from the pump during operation. These could be indicative of underlying mechanical issues that require attention.
- Testing performance: Periodically test the pump's performance parameters, such as flow rate and pressure, to ensure they meet the desired specifications. Adjustments can be made as needed to maintain optimal performance.
- Scheduled maintenance: Implement a planned maintenance program to ensure that maintenance tasks are performed regularly and consistently. Keep detailed records of maintenance activities for reference and analysis.

To learn more about wastewater pumps, check out the following guide: The Ultimate Guide to Wastewater Pumps [An Pump Machinery, Jan 2025]

13.1.2 Valves

13.1.2.1 Check valves

Check valves are used on the discharge side of many pumps to protect the pump against reverse flow when it stops running. [WWTF 2 Ch7 p80 para5]

13.1.2.2 Ball valves

- Design
    - Structure: A ball valve consists of a spherical ball with a hole through its center. The ball rotates to open or close the valve.
    - Types: includes floating ball, trunnion-mounted, and full-bore/reduced-bore designs
- Purpose
    - Function: Primarily used for on/off control of fluid flow. They provide tight sealing and are suitable for high-pressure applications.
    - Advantages: quick operation (quarter-turn), reliable sealing, and low pressure drop when fully open
- Proper placement:
    - Installation: Typically installed in pipelines where a quick shut-off is required. Ensure the flow direction aligns with the valve markings to avoid operational issues.

13.1.2.3 Electronically actuated valves

- Design
    - Structure: These valves are equipped with an electric actuator that converts electrical energy into mechanical motion, allowing the valve to open or close.
    - Types: includes quarter-turn (rotary) and linear actuators
- Purpose
    - Function: Used for automated control of valve operations, often in remote or hard-to-reach locations.
    - Advantages: precise control, integration with control systems, and reduced manual intervention
- Proper placement
    - Installation: Mounted on valves in systems requiring automated control. Ensure compatibility with the valve type and proper electrical connections.

13.1.2.4 Diversion Valves

- Design
    - Structure: Diversion valves have multiple ports and are designed to direct flow from one inlet to numerous outlets or vice versa.
    - Types: includes 3-way and 4-way valves, often used in fluid handling systems
- Purpose
    - Function: Used to change the direction of fluid flow within a system, allowing for flexible operation and maintenance.
    - Advantages: versatile flow control, easy to switch between different flow paths
- Proper placement

- Installation: Placed at points where the flow direction needs to be changed or diverted. Ensure proper alignment and secure connections to prevent leaks.

13.1.3 Water meters

Water meters are installed by the water utility or water service provider for every building to track water consumption for billing purposes. Water meters can be automated and can transmit hourly water use data to the water utility's billing system via a wireless network. This enables property owners to access detailed daily and monthly water usage reports. Having access to accurate water usage information enables property owners to monitor usage and identify possible leaks more quickly than was possible with manually read meters. To prevent injury and damage to equipment, water meters should only be accessed by skilled staff from the water utility. [San Francisco Water Power Sewer, About Your Water Meter, n/d]

In addition, buildings with ONWS may have flow meters 1) on the treated water distribution system as close as possible to the exit to the end use and 2) on the potable makeup water pipeline to the ONWS. [SFDPH Directors Rules and Regulations p11]. Flow meters should undergo regular calibration checks, and operators should maintain calibration records. [SME input]

13.1.3.1 Types of flow meters

Electromagnetic flow meter design:

- Structure: uses a magnetic field and electrodes to measure the flow rate of conductive fluids
- Components: consist of a flow tube, magnetic coils, and electrodes
- Purpose
    - Function: ideal for measuring the flow of water and wastewater due to their accuracy and reliability
    - Advantages: no moving parts, minimal maintenance, and unaffected by fluid properties like viscosity and density
- Proper placement
    - Installation: typically installed in pipelines with a complete pipe condition; ensure proper grounding and alignment with the flow direction

Ultrasonic flow meter design:

- Structure: uses ultrasonic sound waves to measure the velocity of fluid flow
- Components: includes transducers, a flow tube, and a signal processor
- Purpose:
    - Function: suitable for measuring flow in clean and dirty fluids, including wastewater
    - Advantages: nonintrusive, can be installed externally, and provides accurate measurements
- Proper placement:
    - Installation: can be clamped onto the outside of the pipe or inserted into the flow stream; ensure proper alignment and calibration

Mechanical flow meter design:

- Structure: uses mechanical components like turbines, gears, or paddles to measure flow rate
- Components: includes a flow tube, mechanical rotor, and readout device
- Purpose:
    - Function: commonly used for measuring flow in smaller systems or where cost is a concern
    - Advantages: simple design, easy to install, and cost-effective
- Proper placement:
    - Installation: Installed directly in the pipeline. Ensure the flow direction aligns with the meter's markings and avoid placing it near bends or obstructions.

Vortex flow meter design:

- Structure: measures flow rate by detecting vortices shed by a bluff body placed in the flow stream
- Components: includes a bluff body, sensors, and a flow tube
- Purpose:
    - Function: suitable for measuring flow in a variety of fluids, including water and wastewater
    - Advantages: reliable, accurate, and can measure both liquid and gas flow
- Proper placement:
    - Installation: installed in a straight section of the pipeline to ensure precise vortex formation; avoid placing near bends or flow disturbances

General tips for flow meter placement:

- Straight pipe runs: Ensure there are sufficient straight pipe runs upstream and downstream of the meter to minimize flow disturbances.
- Accessibility: Place meters in accessible locations for easy maintenance and calibration.
- Proper sizing: Select a flow meter that matches the pipe size and expected flow rates.

General troubleshooting involves ensuring that there is a flow present. If no flow is present, the meter is not operating and should be replaced.

13.2 Asset management responsibilities

A well-maintained ONWS will have a plan that prioritizes maintenance based on maintaining system reliability and accounting for potential cascading effects resulting from inadequate maintenance. Successful implementation of the plan will require that the necessary resources – personnel, training, funds, information, and infrastructure - are available.

Typical maintenance activities include routine maintenance, preventative maintenance, equipment repair, and equipment replacement.

Routine maintenance: Routine (or daily) maintenance is performed by operators and includes responsibilities such as monitoring and responding to alarms, reviewing operational logs, performing housekeeping, and conducting walkthroughs of the ONWS. Online analyzer readings should also be checked and verified. Buffers and reagents should be refilled as required. If maintenance-related issues are observed, operators should document them and circulate the information to the appropriate personnel for scheduling.

Preventive maintenance: The best-maintained ONWS systems have operations and management (O&M) staff who 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 the risk of failure. Maintenance schedules should be developed for each asset, categorizing tasks as Daily, Weekly, Monthly, or periodic. A Computerized Maintenance Management System is recommended to facilitate this type of program.

Equipment repair: Operators 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 with the operation of the ONWS.

Equipment replacement: The replacement of equipment is an activity determined by 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. [NBRC Guidance Manual p76-77]

Daily	Weekly
– 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, chlorine residual) – Check and record chemical levels – Check for any unusual noises or vibration on equipment	– Check chemical levels and fill as needed – Drain condensate from air receivers – Perform any required grab sampling (e.g., total coliform, BOD) – Check biomass color and MLSS and any signs of foaming – Inspect screens for any buildup of debris
Monthly	**Periodically**
– 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 and clean sleeves if necessary	– Perform chemical cleans on membranes – Replace UV lamps as needed (typically 12-18 months) – Replace or refurbish analytical probes as required

TABLE 13.1: *Examples of routine operations and maintenance activities [NBRC ONWS Guidance Manual p77 Table23]*

In addition, property owners and operators should collaborate to ensure that staff receive proper training in safe operations, water treatment, and regulatory compliance. Operators should have the opportunity for multiple trainings with equipment manufacturers as needed. Supporting building staff should be trained on how to handle routine maintenance (e.g., visual checks for obvious issues such as leaks, olfactory checks, or auditory checks for abnormal equipment sounds), as this can help avoid paying for additional operator visits and provide early warning of potential problems.

Operators should also develop a staffing plan to identify time commitments and the type of staff needed. The staffing plan should identify a backup operator for vacation or other coverage needs, as issues cannot be resolved quickly if they're unavailable.

Furthermore, operators and building owners should agree on a plan to respond to unforeseen expenses (e.g., maintaining a reserve budget or implementing a process for approving emergency budget needs) ahead of time. [SFPUC Lessons Learned Guidebook p11-12]

Operators should work with building occupants and other building maintenance staff (e.g., janitorial, dining services) to provide education about items that should not be flushed into the ONWS (e.g., chemicals that kill biomass, flushable wipes, care products, etc.).

13.3 Storage tank fundamentals

Onsite water storage allows water to accumulate until it is needed. For rainwater, the larger the storage tank, the greater the potable offset that can be achieved. For an ONWS that is providing treatment, a treated water storage tank is recommended. Having this type of tank allows water to be treated at a rate slower than the rate at which it will be used, thereby reducing treatment costs. Additionally, having this tank simplifies the process of providing a makeup water supply. [Austin ONWS Guidebook p10 numbered list]

Flow equalization tanks are covered in more detail in Section 5: Flow Equalization and Pretreatment.

13.3.1 Tanks

13.3.1.1 Overview

Storage tanks in onsite non-potable water reuse systems are designed to hold treated water for various non-drinking purposes, such as irrigation and toilet flushing. These tanks are typically made from durable materials, such as polyethylene, fiberglass, or concrete, to withstand environmental conditions and prevent contamination.

FIGURE 13.2: *Tanks used for storing water in an ONWS [Photo credit: Cathy Dacanay, Chemsearch Fe]*

13.3.1.2 Sizing

The size of the storage tank depends on the expected water demand and the volume of water available for reuse. Proper sizing ensures that the system can meet peak usage periods without running out of water.

13.3.1.3 Structure

The tank's structure includes features such as inlet and outlet pipes, overflow mechanisms, and access points for maintenance. Tanks are often buried underground or placed in secure locations to protect them from physical damage and environmental factors.

13.3.1.4 Leak prevention

Leak prevention is crucial for maintaining the system's efficiency and safety. This involves regular inspections, using high-quality seals and fittings, and ensuring proper installation. Additionally, monitoring systems can detect leaks early, allowing for prompt repairs.

13.3.2 Tank Cleaning Considerations

13.3.2.1 Steps in cleaning

Cleaning storage tanks in ONWS involves several steps to ensure the water remains safe and the system operates efficiently. The process typically includes:

- Draining the tank: Empty the tank to access all surfaces.
- Removing debris: Use a high-pressure hose or pressure washer to remove loose debris, dirt, and any organic matter.
- Disinfecting: Apply a disinfectant, such as liquid sodium hypochlorite (bleach), to kill any remaining bacteria. Ensure the disinfectant is thoroughly mixed and allowed to sit for a specified period.
- Rinsing: Thoroughly rinse the tank to remove any residual disinfectant.
- Refilling: Refill the tank with clean water and resume normal operations.

13.3.2.2 Frequency of Cleaning

Cleaning ONWS storage tanks is relatively uncommon and typically only necessary under specific circumstances, such as:

- Contamination: if water quality tests indicate the presence of harmful bacteria like Total Coliform or E. coli
- Flooding: if the area around the tank has been flooded
- Odor or taste changes: significant changes in the taste or odor of the water

- Repairs: after major repairs to the well casing or pump
- Regular inspections and preventive maintenance can help minimize the need for frequent cleanings, ensuring the system remains efficient and safe.

13.3.3 Level measurements

13.3.3.1 Level Control in ONWS

- Purpose:
  - Function: Level control is essential for maintaining the appropriate water levels in storage tanks and treatment units, ensuring efficient operation and preventing overflow or dry running.
  - Advantages: It helps optimize system performance, conserve water, and protect equipment from damage.
- Components:
  - Level sensors:
    - Types: includes float switches, ultrasonic sensors, and pressure transducers
    - Function: detects the water level and sends signals to the control system
  - Control systems:
    - Types: PLCs (Programmable Logic Controllers) or dedicated level controllers
    - Function: processes signals from level sensors and controls pumps, valves, and alarms
  - Pumps and valves:
    - Role: activated or deactivated based on the water level to maintain desired levels
- Proper placement:
  - Level sensors: Installed at critical points in storage tanks and treatment units to monitor water levels accurately.
  - Control systems: Located in accessible areas for easy monitoring and maintenance.
  - Pumps and valves: Positioned to ensure efficient water transfer and control within the system.
- Best practices:
  - Regular maintenance: Periodically check and calibrate sensors and control systems to ensure accurate readings and reliable operation.
  - Redundancy: Implement backup sensors and alarms to prevent system failures and ensure continuous operation.
  - Integration: Ensure level control systems are integrated with the overall water reuse system for seamless operation. [San Francisco Public Utilities Commission, Onsite Program Guidebook, 2022]

13.3.4 Vector control

ONWS should be constructed and maintained to prevent mosquito harborage. All drains, vents, and other conduits that lead to the system reservoir or collection tank should be screened with a durable fine mesh sized not greater than one-sixteenth of an inch. The mesh should be firmly installed in an area that is easily accessible for cleaning, inspection, and replacement. No gaps should exist around the mesh. All annular gaps around pipes feeding the storage tank(s) should be sealed with a durable, waterproof, nonporous material. A durable gasket with no gaps should be installed around the door openings to the tank(s). Other gaps to the tank(s) should either be sealed or screened as specified above.

The operator should be knowledgeable or be able to contract with a contractor/entity knowledgeable in recognizing all mosquito life stages, understanding the mosquito life cycle, and applying the proper treatment to all life stages. This person shall be available to check the system for signs of harborage, respond to complaints of adult mosquitoes, and arrange proper treatment to eliminate mosquitoes. The use of any pesticide should comply with all local, state, and federal laws. [SFDPH Directors Rules and Regulations p12-13]

13.3.5 Ventilation and odor control

Odor issues can cause problems for public acceptance and, more acutely, affect building occupants if not adequately controlled. Design engineers should design odor management systems, but operators should also take steps to prevent odors from occurring. [SME input]

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). [NBRC ONWS Guidance Manual p53]

As discussed in previous sections, biological treatment plays a critical role in reducing BOD, TSS, and odor. [NBRC ONWS Guidance Manual p65] Checking for odors should be part of the daily maintenance activities. [NBRC ONWS Guidance Manual p77]

13.4 Backflow prevention

13.4.1 Overview

Preventing backflow between ONWS 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. [NBRC ONWS Guidance Manual p12 para3 + bullets, p13 para1]

Backflow prevention devices should be installed before using an ONWS to prevent the regurgitation of debris, chemical contaminants, and waterborne pathogens. During construction, water may be supplied through temporary connections to either the water supply or a segment of the building's water system that is already connected and active. Regardless of the option used, backflow prevention should be practiced and may be required by code. [IAPMO Construction Practices for Potable Water Manual p14 para2-3] When backflow occurs, non-potable water from the ONWS flows back into the potable water distribution system. Any contaminants from the non-potable can then flow into the whole potable distribution system, possibly causing illness or death. [sfpupc.gov Cross Connection p2 para1]

13.4.2 Cross-connection

13.4.2.1 Overview

Cross-connection occurs when there is "an unprotected actual or potential connection between a potable water system used to supply water for drinking purposes and any source or system containing unapproved water or a substance that is not or cannot be approved as safe, wholesome, and potable." [sfpuc.gov CCC Manual for public WQD-2014]

Operators may be responsible for facilitating Inspections and certifications with local jurisdictions and certified inspectors. It is generally not the operator's responsibility to inspect and maintain these devices, as they often require special training and certification.

FIGURE 13.3: *Example of an air gap protecting the potable water supply from potential backflow [Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

13.4.2.2 Testing

Cross-connection testing should be completed in compliance with local and state regulations before the system's initial operation and at mandated intervals thereafter.

13.4.3 Air Gap

ONWS typically include municipally supplied makeup water via an air gap to a break tank, served from the final treated water storage tank, or from an air gap directly to the final treated water storage tank. [Austin Ch15-1.Cross-connection regulations]

13.4.3.1 Definition

An air gap is a physical separation between the end of a potable water supply pipe and the highest possible water level in a receiving vessel. It ensures that there is no direct connection between the potable water supply and any potential contaminants, preventing backflow.

13.4.3.2 Purpose

An air gap protects the potable water supply from contamination by ensuring that water can only flow in one direction, preventing backflow.

13.4.3.3 Proper placement

Air gaps are typically installed at points where potable water is introduced into the reuse system, such as at the inlet of storage tanks or treatment units. Height requirements must be met, which means that the air gap must be at least twice the diameter of the supply pipe above the overflow level of the receiving vessel.

13.4.3.4 Regulations

Regulations may vary by location, but generally, an air gap must comply with local plumbing codes and standards. In addition, commonly referenced standards include those from the American Society of Plumbing Engineers (ASPE) and the Uniform Plumbing Code (UPC). Finally, regular inspections are required to ensure the air gap remains unobstructed and effective.

13.4.4 Prevention devices

13.4.4.1 DC backflow prevention device

A Double Check (DC) backflow prevention device consists of two independent check valves in series. It prevents backflow by ensuring that water flows in only one direction, protecting the potable water supply from contamination. In an onsite non-potable reuse system, DC devices are typically used where there is a low to moderate risk of contamination, such as in irrigation systems.

13.4.4.2 RPZ backflow prevention device

A Reduced Pressure Zone (RPZ) backflow prevention device, also referred to as RP in Table 13.2, includes two internally loaded check valves and a pressure relief valve between them. It provides the highest level of protection against backflow by maintaining a reduced pressure zone that prevents contaminated water from entering the potable water supply. RPZ devices are used in onsite non-potable reuse systems where there is a higher risk of contamination, such as in systems that handle reclaimed water for toilet flushing.

Additionally, it is typical that each municipal water connection (excluding fire services) serving properties with an ONWS be protected by an RPZ.

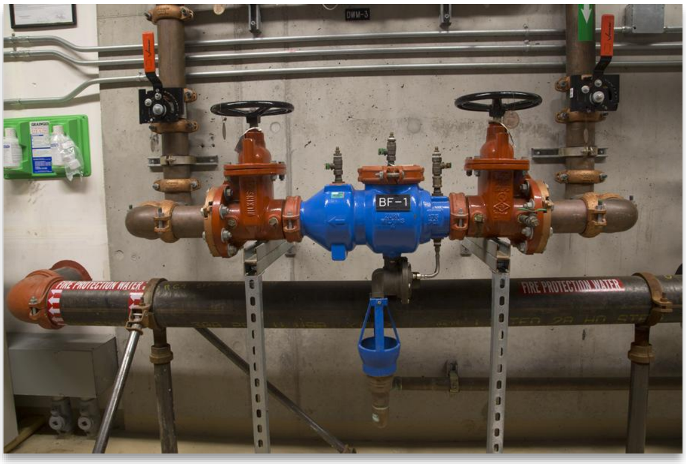


***Figure 13.4:** Reduced-pressure backflow prevention device* *[Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

These devices are crucial for ensuring the safety and integrity of water reuse systems by preventing cross-contamination between potable and non-potable water sources.

13.4.5 Inspection

All buildings must have cross-connection control programs in place and must apply backflow prevention as specified in the governing code. Cross-connections and backflow risks are never acceptable, even in temporary plumbing installed for use during construction. [IAPMO Construction Practices for Potable Water Manual p30 para4 (107.6)]

Locations often associated with cross-connections that should be explicitly addressed in cross-connection control include, but are not limited to:

- Connections to non-potable water systems
- The main water intake
- Fire suppression system off-takes

Cross-connection inspections can occur during and/or after construction is complete. [NBRC ONWS Guidance Manual p 89] When building plumbing systems are altered, cross-connection inspections should occur, and cross-connection testing may be required. [SME input]

Inspections should be implemented to:

- Identify and, if found, disconnect cross-connections
- Identify and, if found, remediate configurations/connections with the potential for backflow

[IAPMO Construction Practices for Potable Water Manual p30 para4 (107.6)]

The operator of the ONWS should work with the property owner and/or building management to remediate any cross-connections found during inspection. If a property owner refuses or fails to eliminate a cross-connection, the authority having jurisdiction may proceed with enforcement activities in accordance with local regulations. [SME input;]

Backflow and backflow prevention are defined and described in plumbing codes. When cross-connections are found, affected system segments need to be disinfected and flushed. [IAPMO Construction Practices for Potable Water Manual p30 para5]

Cross-connection inspections should occur during and/or after construction is complete, including the cross-connections and the installation of other required features, such as backflow prevention devices. Multiple inspections are helpful to identify issues before construction is completed. Other inspections need to be completed to validate the construction of an ONWS and should be encouraged to facilitate a working relationship between the project team, regulators, and program administrators. [NBRC ONWS Guidance Manual p89 para5]

UN Plaza Foundation drainage project – Market Street *[Photo credit: Taylor Nokhoudian]*

Test Your Knowledge

Section 13: Basics of Collection, Distribution, and Storage

1. What functions do pumps provide in an ONWS? (Select all that apply.)
   A. Move water through the collection system
   B. Move treated water from the storage tank to end uses (e.g., toilets)
   C. Meter chemicals into tanks or processes
   D. Increase the elevation of water in a tank or distribution box so it can flow by gravity to downstream processes
2. What are the advantages of using an electronically actuated valve?
   A. Reliable sealing and low pressure drop when fully open
   B. Versatile flow control and easy to switch between different flow paths
   C. Precise control, integration with control systems, and reduced manual intervention
   D. No moving parts and minimal maintenance
3. Why is backflow protection important in ONWS?
   A. Prevents mosquitoes from entering the collection tank
   B. Protects non-potable water from entering the potable water distribution system
   C. Controls odors from the wastewater treatment
   D. Prevents tank leaks
4. True or False. Cleaning ONWS storage tanks is a common and frequent task, typically performed monthly.
   A. True
   B. False
5. All but the following are typical flow meters.
   A. Ultrasonic
   B. Mechanical
   C. Vortex
   D. Haptic

38 Dolores courtyard in San Francisco, CA, that is capturing rainwater for irrigation *[Photo credit: BAR Architects]*

Section 14
Safety Considerations for Operators

14.1 Environment, Health, and Safety Plan

Every water treatment facility needs an Environment, Health, and Safety Plan to communicate and guide the implementation of environmental protection and workplace safety. From a health and safety perspective, this plan ensures compliance with OSHA regulations and establishes procedures for identifying workplace hazards and mitigating accidents and exposure to hazardous situations.

From an environmental perspective, this plan involves creating a system approach to comply with environmental regulations (e.g., managing air emissions). All operators and personnel working in proximity to an ONWS should be trained to have a sufficient understanding to confidently adhere to the plan. [NBRC ONWS Guidance Manual p78 para5]

14.2 Chemical safety

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 store and handle these chemicals safely. 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. A Safety Data Sheet (SDS)—formerly known as a Material Safety Data Sheet (MSDS)—is a detailed document that provides essential information about a chemical substance or mixture. It is designed to ensure the safe handling, storage, and disposal of hazardous materials in the workplace. 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 the information described in **Table 14.1**. [NBRC ONWS Guidance Manual p78 para5-6, p79 para1] Scheduled drills that simulate chemical spills to test and practice response procedures are also recommended. [SME input]

Hazardous material storage and management
– Provide inventory of hazardous substances and their locations – Provide proper labeling, secondary containment, and compatible storage materials where needed – Follow applicable rules for inspection procedures and documentation
Personal protective equipment (PPE)
– Identify appropriate PPE for each chemical onsite and each activity involving hazardous substances – Store necessary PPE onsite for handling of hazardous materials
Eyewash and shower stations
– Identify appropriate use procedures, station locations, frequency of inspections, and inspection protocols – Provide description of maintenance procedures and frequency
Chemical spill kits
– Store near chemical storage sites – Provide list of spill kit contents for each chemical stored onsite – Inspect kits regularly and document inspection results
Chemical deliveries
– Use licensed carriers to transport hazardous materials – Provide list of chemical suppliers and contact information – Describe procedures for receiving chemical deliveries, including receiving location, minimum training requirements, precautions needed, etc.

***TABLE 14.1**: Examples of considerations for a chemical safety plan [NBRC ONWS Guidance Manual p79 Figure27]*

14.3 Confined space plan

14.3.1 Confined space program for operators

A confined space program is essential for ensuring the safety of operators working in confined spaces within an onsite non-potable water reuse system. Confined spaces are areas large enough for an employee to enter and perform work but have limited or restricted means of entry or exit, and they are not designed for continuous occupancy. Examples include storage tanks, wet wells, and treatment units.

14.3.2 General description

The program aims to identify, evaluate, and control hazards associated with confined spaces. It includes procedures for safe entry, monitoring, and emergency response to protect operators from risks such as toxic gases, oxygen deficiency, and physical hazards.

14.3.3 Components of a confined space plan

A comprehensive confined space plan should include the following elements:

- Identification and classification: List all confined spaces and classify them based on the level of hazard (e.g., permit-required confined spaces).
- Entry procedures: Detailed steps for safe entry, including pre-entry checks, atmospheric testing, and use of personal protective equipment (PPE).

- Training: Regular training for operators on confined space hazards, entry procedures, and emergency response.
- Monitoring: Continuous monitoring of atmospheric conditions within the confined space during entry.
- Emergency response: Clear procedures for rescue operations, including the availability of rescue equipment and trained personnel.
- Documentation: Recordkeeping of all confined space entries, including permits, atmospheric test results, and training records.

14.3.4 Responsibilities

There are different responsibilities associated with the confined space plan, depending on the role a person occupies within the organization.

- Program administrator: Responsible for developing, implementing, and maintaining the confined space program. This includes ensuring compliance with regulations, conducting regular reviews, and updating procedures as needed.
- Supervisors: Ensure that entry procedures are followed, conduct pre-entry briefings, and verify that all necessary equipment and personnel are available.
- Operators: Follow entry procedures, use PPE, and report any hazards or incidents.
- Emergency response team: Trained personnel ready to respond to confined space emergencies, equipped with rescue tools and knowledge of rescue procedures.

Implementing a confined space program is crucial for the safety and efficiency of operators working in onsite non-potable water reuse systems.

14.4 Electrical Safety

Electrical Safety in ONWS

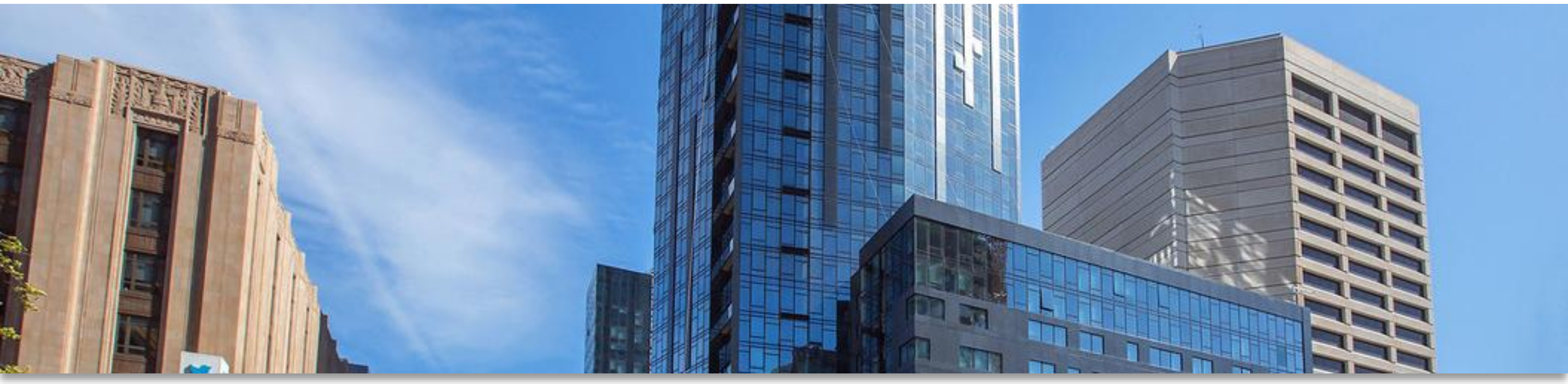
- ONWS incorporates various electrically powered components, including pumps, control panels, sensors, and treatment units. Ensuring electrical safety is essential to protect workers, maintain system integrity, and prevent accidents.

Key Safety Considerations:

- Water and Electricity Separation
  - Electrical components must be properly sealed and rated for wet environments to prevent short circuits and electrical shock. Use waterproof enclosures and ensure cables and connectors are protected from moisture.
- Grounding and Bonding
  - All electrical systems should be properly grounded to prevent shock hazards. Bonding ensures that all conductive parts are electrically connected, reducing the risk of stray voltage.
- GFCI Protection
  - Ground Fault Circuit Interrupters (GFCIs) should be installed in areas where electrical equipment is exposed to moisture. These devices quickly shut off power if a ground fault is detected, minimizing the risk of electrocution.
- Routine Inspections and Maintenance
  - Regular inspections should be conducted to check for corrosion, damaged insulation, loose connections, and moisture intrusion. Preventive maintenance helps identify and resolve issues before they become hazards.
- Training and Signage

- Personnel should be trained in electrical safety procedures, including emergency response and equipment handling. Clear signage should indicate high-voltage areas, emergency shutoffs, and restricted zones.

- Lockout/Tagout (LOTO)
  - Lockout/Tagout (LOTO) is a critical safety procedure that ensures electrical energy sources are properly shut off and cannot be accidentally reenergized during maintenance or servicing.
  - LOTO Process:
  - Lockout: Physically locking the power source in the "off" position using a padlock or similar device.
  - Tagout: Attaching a tag to the locked device that clearly states who locked it out, the reason, and the date/time.
  - Why LOTO Matters:
    - Prevents accidental startup of equipment while maintenance is being performed.
    - Protects workers from electrical shock, burns, or mechanical hazards.
    - Ensures clear communication and accountability during service operations.
    - Best Practices:
      - Only authorized personnel should perform LOTO procedures.
      - Use standardized locks and tags with clear, identifiable markings.
      - Verify that all energy sources are isolated before beginning work.
      - Maintain a written LOTO policy and train all staff on its use.



NEMA Building in San Francisco, CA, that piloted a distributed Epic Cleantec solids handling system designed to capture, process, recover, and reuse solid waste from the building's wastewater collection system [Photo credit: Epic Cleantec]

Test Your Knowledge

Section 14: Safety Considerations for Operators

1. What is an environment, health, and safety plan?

   A. Detailed plan for start-ups and shutdowns of the ONWS

   B. Describes the staffing needs for operating the ONWS

   C. Lists the critical control parameters and response conditions

   D. Ensures compliance with OSHA regulations and creates procedures for identifying workplace hazards and reducing accidents and exposure to harmful situations

2. Examples of information included in a chemical safety plan include the following: (Select all that apply.)

   A. Turbidimeter calibration procedures

   B. Identification of appropriate PPE

   C. Inventory of hazardous substances

   D. Information on non-flushable items

3. What should an operator be aware of when working in confined spaces? (Select all that apply.)

   A. Confined space hazards

   B. Car alarm sounds

   C. Entry procedures

   D. Emergency response

4. Which of the following does not need to be included in chemical safety records?

   A. Weekly hazardous material inspection logs

   B. Chemical release assessment and reporting records

   C. Design of the ONWS disinfection system

   D. Hazardous waste manifests

5. The acronym SDS refers to which of the following terms?

   A. Site Detail Survey

   B. Safety Data Sheet

   C. Sorted Department Site

   D. Semi Divided Substructure

Pier 27's rainwater tanks in San Francisco, CA [Photo credit: Port of San Francisco]

Section 15
Operational Considerations to Maintain Aesthetics of Treated Water

15.1 Color and odor control

All ONWS must control odors. Color and odor issues can be a problem for public acceptance, particularly if an ONWS is producing water for end uses with public exposure (e.g., toilet flushing). [SFDPH Directors Rules and Regulations p13 bullet; NBRC ONWS Guidance Manual p13 bullets]

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, graywater). The use of a biological process in the treatment train provides the first barrier against color, and it can be further reduced through the use of a disinfection oxidant (e.g., ozone, chlorine). Filtration technologies (e.g., reverse osmosis, granular activated carbon) will also provide further polishing and color removal. [NBRC ONWS Guidance Manual p39 box]

The most commonly used methods for removing color and odor in an ONWS are reverse osmosis (RO) and granular activated carbon (GAC). Below you will find a brief description of how these two systems control odors and color.

15.1.1 Reverse osmosis (RO)

- Design
  - Structure: RO systems use semipermeable membranes to remove contaminants from water by applying pressure to force water through the membrane.
  - Components: Includes a high-pressure pump, RO membranes, and a permeate collection system.
- Purpose
  - Odor Control: RO effectively removes dissolved organic compounds and other substances that cause odors.
  - Color Control: RO membranes can filter out color-causing particles and dissolved substances, resulting in clear water.
- Proper placement
  - Installation: Typically installed after primary treatment processes to ensure the removal of fine contaminants.
  - Maintenance: Regularly check and replace membranes to maintain efficiency and prevent fouling.

15.1.2 Granular activated carbon (GAC)

- Design
  - Structure: GAC systems use activated carbon granules to adsorb contaminants from water.
  - Components: Includes GAC filters, housing units, and flow control devices.
- Purpose
  - Odor Control: GAC is highly effective at adsorbing organic compounds and chlorine, which can cause odors.
  - Color Control: GAC can remove color-causing substances, such as tannins and humic acids.
- Proper placement:
  - Installation: Often used as a polishing step after primary and secondary treatment processes.
  - Maintenance: Regularly replace or regenerate GAC media to ensure continued effectiveness.
- Best practices:
  - Combination Use: Using RO and GAC in tandem can provide comprehensive odor and color control, ensuring the production of high-quality effluent.
  - Monitoring: Regularly monitor water quality to detect any changes in odor or color and adjust treatment processes accordingly.

The National Museum of African American History and Culture Building features a rainwater harvesting system *[Photo credit: San Francisco Public Utilities Commission. Permission to Use.]*

Test Your Knowledge

Section 15: Operational Considerations to Maintain Aesthetics of Treated Water

1. The color of the treated water can be an issue with what types of ONWS that have higher organic concentrations? (Select all that apply.)

   A. Graywater

   B. Stormwater

   C. Condensate

   D. Blackwater

2. Which of the following treatment processes can be used to remove color effectively? (Select all that apply.)

   A. Biological treatment

   B. Disinfection

   C. Filtration

   D. Aeration

3. True or False. Reverse osmosis systems can effectively control for odor and color.

   A. True

   B. False

4. How do granular activated carbon (GAC) systems work?

   A. Use semipermeable membranes to remove contaminants from the water

   B. Use high pressure to remove contaminants from the water

   C. Use activated carbon granules to adsorb contaminants from the water

   D. Use gravity to remove contaminants from the water

5. How often do GAC media need to be replaced?

   A. Never

   B. Twice a year

   C. Every two years

   D. Regularly

MBR system at Mission Rock in San Francisco, CA *[Photo credit: San Francisco Public Utilities Commission]*

Section 16
Commissioning and Shutdown/Start-ups

A commissioning plan is a risk management plan developed to help operators identify risks to water quality and water safety before the occupancy of the building, and it provides clear procedures for managing the risk at different points in the building lifecycle, including start-up, normal operation, under occupancy, water system shutdown, and water system restart. This plan can be used to manage any health risk associated with the loss of chemical or microbiological water quality or with water safety concerns. [IAPMO Construction Factors for Potable Water Management p6 para1]

Each ONWS should include a well-thought-out plan to commission the ONWS as well as prepare for system outages, including specific contingencies to address loss of service due to planned or unplanned shutdowns of the project, such as:

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

[WE&RF Final Report p69 para2 + bullets]

16.1 Systems documentation

ONWS operators are responsible for maintaining all documents related to operating procedures, which include. Still, they are not limited to, detailed startup and shutdown procedures, operator logbooks and checklists, the ONWS operations and maintenance manual, and troubleshooting procedures. They are also responsible for being knowledgeable about and having access to all equipment manuals. [NBRC ONWS Guidance Manual p73 + bullets]

Membrane Filtration (MF)

System Readiness Checklist (Perform Prior to Inspection):

- Daily pressure decay tests (PDTs) have been conducted for at least one week and meet minimum design requirements
- The backwash sequence has been tested and verified to function properly
- At least one chemical clean (e.g., enhanced flux maintenance or maintenance clean) has been documented and verified to function properly
- One CIP sequence has been conducted and verified to function properly

Inspection Checklist:

- An exceedance of the instantaneous filtrate turbidity high alarm level triggers an alarm.
- An exceedance of the instantaneous filtrate turbidity high high alarm level triggers an alarm and the system initiates the proper automatic response (e.g., unit shutdown).
- An exceedance of the 95th percentile filtrate turbidity high alarm level triggers an alarm.
- An exceedance of the 95th percentile filtrate turbidity high high alarm level triggers an alarm and the system initiates the proper automatic response (e.g., unit shutdown).
- The calculated LRV low low alarm level is triggered by an off-specification PDT result and the system initiates the proper response (e.g., until shutdown).

Figure 16.1: *Example of an operator's checklist for commissioning a membrane filter as part of an ONWS [San Francisco Public Utilities Commission]*

16.2 Commissioning

16.2.1 Overview

Commissioning an ONWS involves the activities required to bring the system into normal working conditions, whether it is a new system or the recommissioning of a previously nonoperational system. [WE&RF Final Report pxvii Terminology]

The operator may be responsible for these activities. Other entities may also be responsible for the start-up and commissioning of an ONWS, such as design engineers and system manufacturers.

Start-up and commissioning are the processes of preparing an ONWS for operation and confirming the system can meet regulatory requirements and design specifications during ongoing operation. Those constructing and commissioning an ONWS must complete specific steps before moving forward with the project. For example, commissioning is typically completed in collaboration with local/state regulators, who have the final approval once commissioning is complete and the ONWS is allowed to begin normal operation. It is essential to comply with local regulations. [Guidebook for Commissioning an ONWS in San Francisco p3 col2 para1]

The Guidebook for Commissioning an ONWS in San Francisco has additional information on this topic.

16.2.2 Commissioning Data and Performance Validation

During system commissioning, the operator should conduct initial checks and verifications needed before introducing water into the system, including:

- Perform electrical testing to verify proper installation, such as:
  - Power checks
  - Signal wiring termination checks
  - Signal loop checks
  - Control panel input/output checks
- Perform mechanical testing to verify proper installation, such as:
  - Pump and valve checks
  - Hydrostatic and pressure leak testing
- Perform plumbing checks, such as:
  - Backflow prevention device checks
  - Cross-connection test

The purpose of verifying performance capability during commissioning is to confirm that the treatment processes function as designed. Alternate water sources captured for reuse onsite (e.g., blackwater or graywater) are introduced to the onsite water system, but treated water is not yet used in the building and is discharged to the sewer. Once the first treatment process is confirmed to be meeting design requirements, effluent from that process is introduced to the second treatment process. This pattern continues until all treatment processes are brought online and can demonstrate proper function. System performance and effluent water quality are confirmed through online analyzers, hand-held analytical instruments, and laboratory analysis. The overall system controls are also tested during this stage (e.g., diversions, critical alarm shutdown, etc.). Upon completion, the onsite water treatment system should be operational, treating source water, and meeting the design specifications and regulatory requirements.

Actions include:

- Perform wet testing of treatment processes
- Conduct initial instrument calibration
- Verify that each treatment process responds appropriately to controls and alarms
- Test interfaces between treatment processes and systemwide communication (e.g., downstream process response to failures upstream)
- Perform sequence testing of treatment processes (e.g., backwash cycle on a membrane filtration process) and the overall treatment system (e.g., treatment processes can shut down in the correct sequence)
- Operate treatment processes in various modes: local manual mode (controlled manually at the treatment process level), remote manual mode (controlled manually via SCADA), and remote automatic mode (controlled automatically via SCADA)
- Verify the operation of chemical skids

The operator should work with the design engineer to verify the performance capability, ensuring the protection of equipment and adherence to manufacturer warranties. Additionally, the duration and complexity of verifying performance capability can vary significantly depending on the treatment process. For example, a biological process (such as an MBR) may require multiple weeks or months to establish a stable population of microorganisms needed to meet treatment standards. [Guidebook for Commissioning an Onsite Water Reuse System in San Francisco p 4-5] [Austin Onsite Water Reuse Guidebook p16 Table, p17 Table, p20 col1 para1 + Table]

In a biological system, the operator must observe the biomass and perform regular settlability tests to ensure that sufficient microbiology is present for treatment before allowing water to be processed for reuse. Once a suitable level of solids production has been achieved, the plant is considered ready for treatment, provided that all other start-up checks and tests have been completed.

16.2.3 First start-up in the permitting process

An effective permitting process provides regulators and program administrators with several opportunities to evaluate projects and confirm compliance with ONWS requirements, which helps ensure the program's success by fostering good communication between those responsible for the design, construction, and operation of the facility. [NBRC ONWS Guidance Manual p83 para2]

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

TABLE 16.1: *Reports submitted and issued as part of the process to approve a decentralized non-potable water system [WE&RF Final Report pES-5 Table ES-2]*

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16.2.4 Plant seeding

Plant seeding involves providing a biological seed to get the biological systems started on the right track. It is not a substitute for treatment. [SME input]

Seeding is the process of introducing a healthy population of microorganisms into a biological treatment system to initiate or restore microbial activity. This is essential for systems like Membrane Bioreactors, where microbes are responsible for breaking down organic pollutants.

Key Aspects:

Purpose: To establish a robust microbial community capable of degrading organic matter, nutrients, and other contaminants in wastewater.

When to Seed:

- During system start-up.
- After system cleaning or disinfection.
- Following a toxic shock or prolonged inactivity.

Sources of Seed Material:

- Activated sludge from a municipal wastewater treatment plant.
- Commercial microbial inoculants (available in liquid, powder, or tablet form).
- Effluent or sludge from a healthy, similar onsite system.

Application:

- Introduce the seed material directly into the aeration or treatment tank.

- Ensure good mixing and aeration to help microbes acclimate and colonize.

Environmental Conditions:

- Maintain optimal pH (6.5–8.5), temperature (20°-35°C), and dissolved oxygen (>2 mg/L).
- Avoid introducing toxic chemicals or disinfectants during the seeding period.

Stabilization Period:

- It may take several days to a few weeks for the microbial population to stabilize and reach full treatment efficiency.

16.2.5 Shutdown Conditions

Operators may need to perform the following actions during shutdown conditions when the ONWS is not operating and diverting water to the sewer: managing diversions, addressing critical equipment failures, and implementing bypasses.

16.2.6 Diversions and Bypasses

An operator will need to know when diversions or bypasses are necessary and how to implement them. A system designed to meet the minimum LRTs without any redundancy or buffer will need to divert treated effluent to the sewer whenever there is a treatment excursion, since this action will cause the LRTs to drop below the minimum requirement. [NBRC ONWS Guidance Manual p60 para2]

Most ONWS are equipped with electronically actuated valves that can be manually or automatically operated to divert flow to the sewer during an off-spec water event or during both planned and unplanned shutdowns. Operators should consider whether placing diversion valves in manual mode will disrupt normal system operations. Typically, ONWS systems have programming that automatically diverts off-spec and influent water to the sewer. See below for additional details. Automated diversion refers to the system's capability to automatically cease the delivery of onsite treated non-potable water upon indication that it does not meet pathogen log reduction targets, based on continuous process verification monitoring. In this case, water is diverted to the community sewer system for disposal or recirculated to the beginning of the treatment process. Automatic diversion can add to costs and overall complexity, but it provides the benefit of continuous operation and the potential for the system to return to its specifications and begin treating automatically. [SME input]

The capability of systems to perform automatic diversions is dependent on the programmable logic controllers (PLCs) connected to various ONWS components. The PLC is programmed to provide instructions to the components based on online monitoring feedback, maintaining the system within the desired range of operating conditions. It is through the PLC that operators can see process performance data; modify operational setpoints; and initiate cleans, diversions, and shutdowns. [NBRC ONWS Guidance Manual p74 para4]

Any time a bypass occurs, it should be reported to the regulator, as well as documented in the logbook onsite. [NBRC Guidebook for Developing/Implementing Regulations for ONWS p14 col2 para2; SFDPH Directors Rules and Recommendations p18 para3; WE&RF Final Report p74 para1]

Each ONWS should be designed to allow for both system overflow and system bypass, enabling water to flow to either the sanitary sewer system or storm sewer system, depending on the source of the water. Overflow enables an operator to take the system offline for maintenance; the storage tank is allowed to overflow and drain without causing other problems. Alternatively, a bypass enables an operator to divert influent water directly to the drain. Treated water diversion valves can be used to discharge improperly treated water (i.e., water that does not meet the critical surrogate parameters) to drain and not reuse it.

Rainwater, condensate, and foundation drain water systems:

- Overflow is piped to the storm sewer through an approved backwater valve or air gap. Overflow can also be sent to an infiltration location or to the landscape.
- Bypass is diverted directly to the storm sewer, infiltration location, or landscape.

Stormwater, graywater, and blackwater systems:

- Stormwater overflow or bypass is piped to the storm sewer through an approved backwater valve or air gap. Overflow can also be sent to an infiltration location or to the landscape.
- Graywater or blackwater overflow is piped to the sanitary sewer through an approved backwater valve or air gap. Bypass is diverted to the sanitary sewer [Austin Onsite Water Reuse Guidebook p31 para4 + bullets, SME input]

16.2.7 Critical equipment failure

During commissioning, the operator needs to verify that the onsite water system responds correctly to water quality exceedances and treatment process failures. The system does not require an actual failure mode for this verification; instead, signals can be manipulated to simulate a scenario in which a public health threshold has been exceeded, resulting in a system response, such as a diversion. To simulate a failure condition, the operator can manipulate source signals (i.e., the outputs from an instrument) or control signals (i.e., inputs to the programmable logic controller (PLC) or HMI) to induce a simulated failure. To achieve this, the PLC could force an output signal from a given control point monitor outside of its range, such as causing an RO conductivity meter to display an unacceptable reduction in conductivity through the process. This action should trigger an alarm and elicit a specific system response (e.g., diverting the off-spec water to the sewer). It's also possible for the operator to simulate failures by adjusting alarm setpoints. For example, the setpoint for minimum free chlorine residual could be adjusted to a value above the current reading to simulate a failure to meet the threshold. This setpoint adjustment should then cause the system to respond to the forced "failure" and provide an opportunity to confirm the appropriateness of the response. [NBRC Guidance Manual p13]

During ongoing operations, operators must report all critical equipment failures and system malfunctions to the regulatory agency in addition to addressing the failures. The failures need to be addressed before distributing treated water in the building. As a matter of standard practice, all of these types of events should be recorded in a logbook that is kept onsite. [SFDPH Directors Rules and Recommendations p22 para4; SME input]

A reverse osmosis system is being used to treat blackwater at Mission Rock in San Francisco, CA *[Photo credit: San Francisco Public Utilities Commission. Permission to use.]*

Test Your Knowledge

Section 16: Commissioning and Shutdown/Start-ups

1. A commissioning plan helps operators in which of the following ways: (Select all that apply.)
   A. Provides locations of all chemical spill kits
   B. Provides direction on how to replace a lamp in a UV reactor
   C. Provides clear procedures for restarting the ONWS
   D. Identifies risks to water quality and water safety before occupying the building
2. Start-up and commissioning are the processes of preparing the ONWS for what?
   A. To go on standby
   B. To operate to meet regulatory requirements and design specifications
   C. To recirculate
   D. To divert to the sewer
3. During system commissioning, what is not an example of an activity performed during plumbing checks? (Select all that apply.)
   A. Presence of irrigation hose bibs
   B. Backflow prevention device checks
   C. Cross-connection test
   D. Temperature of the faucet water
4. True or False. During commissioning, treated blackwater and graywater systems can immediately use the water in the building and are not required to divert it to the sewer.
   A. True
   B. False
5. Sources of plant seed material include all but the following sources.
   A. Activated sludge
   B. Commercial microbial inoculants
   C. Topsoil
   D. Healthy effluent

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Note: this Manual's development follows and is aligned with the development of the following two Exam Specification documents

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Appendix 1: Formula Sheet

STATE WATER RESOURCES CONTROL BOARD
OPERATOR CERTIFICATION EXAMINATION
Equivalents and Formulae Sheet (Revised Jan 2014)

EQUIVALENTS

Note: conc = concentration, L = liter, mg = milligram, ppm = parts per million, psi = lbs/in^2

27 ft^3 = 1 yard^3 1 acre = 43,560 ft^2 1 ft^3 of water = 7.48 gallons 1 gallon of water = 8.34 lbs 365 days = 1 year	1 gram = 1,000 mg 1 ton = 2,000 lbs 1 mg/L = 1 ppm 1 % = 10,000 mg/L π = 3.14	60 min = 1 hour 24 hours = 1 day 1 day = 1,440 min = 86,400 sec 1 ft of H_2O = 0.43 psi 1 lbs/in^2 = 2.31 ft of H_2O
1 HP = 0.746 kW = 550 ft·lb/sec = 33,000 ft-lb/min		
1 Million Gallons/Day (MGD) = 694 Gallons/Minute (gpm) = 1.547 ft^3/sec = 3.069 acre·ft/day		

FORMULAS

Acronym: AST = Activated Sludge Tank, BOD = Biochemical Oxygen Demand, ET = Evapotranspiration, F/M = Food to Micro-organism Ratio, HP = Horsepower, kW = Kilo-Watt, MCRT = Mean Cell Residence Time, MG = Million Gallons, MLSS = Mixed Liquor Suspended Solids, MLVSS = Mixed Liquor Volatile Suspended Solids, Q = flow, RBC = Rotating Biological Contactor, SS = Suspended Solids, TDH = Total Dynamic Head, TF = Trickling Filter, VS = Volatile Solids, WAS = Waste Activated Sludge

Area of Rectangle, {ft^2} = length, {ft} x width, {ft}
Area of Circle, {ft^2} = $\frac{\pi}{4} \times$ [diameter, {ft}]^2 = 0.785 x [diameter, {ft}]^2
Volume of Rectangular or circular tank of uniform depth, {ft^3} = area, {ft}^{2} x depth, {ft}
Volume of Cone, {ft^3} = $\left[\frac{\text{base area, \{ft}^2\text{\} x depth, \{ft\}}}{3}\right]$
Circumference, {ft} = π x diameter, {ft}
Removal efficiency, {%} = $\left[\frac{(\text{in}-\text{out})}{\text{in}}\right] x100$
Velocity, {ft/sec} = $\left[\frac{\text{distance,\{ft\}}}{\text{time,\{sec\}}}\right]$
Detention time, {hr} = $\left[\frac{\text{tank volume, \{ft}^3\text{\} X 7.5 } \{\frac{\text{gallons}}{\text{ft}^3}\} \text{ X 24} \{\frac{\text{hrs}}{\text{day}}\}}{\text{Q, \{gallons/day\}}}\right]$
Q, {ft^3/sec} = velocity {ft/sec} x area {ft^2}
BOD or SS, {lbs/day} = 8.34 {lbs·L/MG·mg} x Q,{MGD} x conc,{mg/L}
Hydraulic loading rate, {gal/day·ft^2} = $\left[\frac{\text{Q total, \{gallons/day\}}}{\text{area, \{ft}^2\text{\}}}\right]$
Digester (VS) loading rate, {lbsVS/day·ft^3} = $\left[\frac{\text{VS added, \{lbs/day\}}}{\text{volume, \{ft}^3\text{\}}}\right]$
Weir overflow rate, {gal/day·ft} = $\left[\frac{\text{Q, \{gallons/day\}}}{\text{weir length, \{ft\}}}\right]$
Solids loading rate, {lbs/day·ft^2} = $\left[\frac{\text{solids applied, \{lbs/day\}}}{\text{surface area, \{ft}^2\text{\}}}\right]$
F/M, {lbs BOD/day·lbs MLVSS} = $\frac{\text{BOD applied \{lbs/day\}}}{\text{MLVSS, \{lbs\}}}$

1

STATE WATER RESOURCES CONTROL BOARD
OPERATOR CERTIFICATION EXAMINATION
Equivalents and Formulae Sheet (Revised Jan 2014)

Q return, {MGD} = $\frac{Q\{MGD\} \times MLSS\left\{\frac{mg}{L}\right\}}{(RAS - MLSS)\left\{\frac{mg}{L}\right\}}$
Organic loading, $\left\{\frac{\{lbs\ BOD/day\}}{\{see\ Units\}}\right\} = \left[\frac{Q\ \{MGD\} \times BOD\ conc, \left\{\frac{mg}{l}\right\} \times 8.34\ \{lbs*L/MG*mg\}}{Volume, \{1{,}000\ ft^3\ (TF),\ \ 1{,}000\ ft^2\ (RBC)\ or\ acres\ (ponds)\}}\right]$
MCRT, {days} = $\frac{MLSS_{aeration\ tank(s)}\{lbs\} + MLSS_{clarifier}\{lbs\}}{SS_{effluent}\left\{\frac{lbs}{day}\right\} + SS_{WAS}\{lbs/day\}}$
SS_{WAS}, {lbs/day} = $\frac{MLSS_{aeration\ tank(s)}\{lbs\} + MLSS_{clarifier}\{lbs\}}{MCRT\ \{days\}} - SS_{effluent}\{lbs/day\}$
Sludge Volume Index {ml/gram} = $\left[\frac{settled\ sludge\ volume, \left\{\frac{ml}{L}\right\} X\ 1{,}000\ \left\{\frac{mg}{gram}\right\}}{MLSS,\ \left\{\frac{mg}{L}\right\}}\right]$
Pump efficiency, {%} = $\left[\frac{Water\ HP}{Brake\ HP}\right] \times 100$
Brake HP {HP} = $\left[\frac{Motor\ Power, \{kW\} \times motor\ efficiency}{0.746\ \{kW/HP\}}\right]$
Water HP {HP} = $\frac{Q, \{gpm\} \times TDH, \{ft\}}{3{,}960\ \{gpm \cdot ft/HP\}}$
% VS reduction {%} = $\left[\frac{VS\ in - VS\ out}{VSin - (VSin \times VSout)}\right] \times 100$
Chlorine demand, {mg/L} = dosage, {mg/L} – residual, {mg/L}
BOD, {mg/L} = $\frac{Initial\ DO\ \{mg/L\} - Final\ DO\ \{mg/L\}}{[Sample\ Size\ \{ml\}/Bottle\ Size\ \{ml\}]}$
Net Reservoir Flow, {inch/day} = $Q_{in} - Q_{out} = Q_{pond}\{inch/day\} + Q_{rain}\{inch/day\} - Q_{ET}\{inch/day\}$
Hydraulic Loading, Pond, {inch/day} = $\frac{Depth\ of\ pond, \{inches\}}{Detention\ time, \{days\}}$

Appendix 2: Glossary

- **Biological Treatment:** also known as *secondary treatment* in an ONWS, is an essential step in the treatment train, particularly when treating blackwater, graywater, and stormwater. Biological treatment steps help remove the following constituents from the source water: Biological oxygen demand, suspended solids, dissolved organic matter, nutrients, pathogens
- **Blackwater:** also known as domestic wastewater, it originates from toilets, urinals, kitchen/utility sinks, and dishwashers; requires the most treatment
- **Commercial building:** building with a commercial use
- **Commissioning:** refers to the period (after ONWS installation & project startup testing) when the fully functioning system is tested to verify that all of the equipment and processes meet the specification of the design / verify the proper functioning of critical system elements (e.g., 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
- **Condensate:** water vapor that is converted to a liquid and collected; most common sources in buildings include air conditioning, refrigeration, and steam heating
- **CT Framework:** the most commonly used disinfection framework, where CT refers to the product of the disinfectant residual concentration (C) and the contact time (T)
- **District-scale project:** an ONWS that covers multiple properties and may cross public rights-of-way
- **Foundation water:** Shallow groundwater collected from drainage around building foundations or sumps
- **Greywater:** wastewater collected from bathroom sinks, showers, bathtubs, clothes washers, and laundry sinks; comes from non-blackwater sources
- **Log Reduction Targets (LRTs):** a way to quantify the treatment needed to make the water safe and fit for the intended use. The LRT requirements depend on the source water quality and the intended end use
  - Using log reduction as the metric, a 1-log reduction corresponds to a 90% (e.g., 10-fold) reduction in pathogens, 2-logs is 99% (e.g., 100-fold), and 3-logs is 99.9% (e.g., 1,000-fold)
- **Membrane Bioreactor (MBR):** an advanced wastewater treatment technology that combines biological treatment with membrane filtration. MBRs combine suspended growth biological treatment with an integrated membrane system to provide enhanced organics and suspended solids removal
- **Multi-family building:** a building that contains three or more dwelling units
- **Mixed-use building:** a building with both residential use and commercial use
- **Onsite non-potable water system (ONWS):** a system in which water from local sources is collected, treated, and used for non-potable uses at the building- to district/neighborhood-scale, generally at a location near the point of generation system stability
- **Primary disinfection:** used to achieve the pathogen log reduction targets for ONWS. Associated with the control of enteric viruses, parasitic protozoa, and enteric bacteria
- **Project Start-up:** the testing period (before commissioning) when the various processes and equipment need to be brought online for the first time to confirm proper installation, calibration, and function. It is also during this time that operators may acclimate processes, such as biological treatment systems
- **Rainwater:** precipitation from rain or snowmelt events collected directly off a roof surface that is not subject to frequent public access
- **Risk-Based Frameworks:** identify a target health benchmark and then calculate the level of treatment needed to achieve that goal
- **Secondary disinfection:** used to maintain a disinfectant residual to prevent contamination as water travels through the distribution system. Provides protection against opportunistic pathogens such as Legionella
- **Stormwater:** precipitation runoff from rain or snowmelt events that flows over land and/or impervious surfaces (e.g., streets, parking lots, rooftops); may include runoff from roofs with frequent public access
- **Telemetry:** process of measuring and monitoring real-time data

- **Turbidity:** a measure of water clarity. In an ONWS, turbidity is a surrogate for membrane integrity and is one of the most common methods to monitor system performance in membrane systems

Appendix 3: Acronyms

- BOD – Biochemical Oxygen Demand
- CECs – Contaminants of Emerging Concern
- CFU – Colony Forming Unit
- COD – Chemical Oxygen Demand
- CT – Concentration and Contact Time; (C) – Concentration; (T) – Contact Time
- DO – Dissolved Oxygen
- EPA – Environmental Protection Agency
- FAC – Free Available Chlorine
- FCR – Free Chlorine Residuals
- GAC – Granular Activated Carbon
- HRT – Hydraulic Retention Time
- LRT – Log Reduction Target
- LRV – Log Reduction Value
- MBR – Membrane Bioreactor
- MF – Microfiltration
- MGD – Million Gallons Per Day
- MLSS – Mixed Liquor Suspended Solids
- MPN – Most Probable Number
- NBRC – National Blue Ribbon Commission for Onsite Water Systems
- ONWS – Onsite Nonpotable Water Systems
- OWRS – Onsite Water Recycling Systems
- PPE – Personal Protective Equipment
- RO – Reverse Osmosis
- SBR – Sequencing Batch Reactors
- SCADA – Supervisory Control and Data Acquisition
- SOP – Standard Operating Procedure
- SRT – Solids Retention Time
- SU – Standard Units
- TC – Total Chlorine
- TCR – Total Chlorine Residuals
- TDS – Total Dissolved Solids
- TOC – Total Organic Carbon
- TSS – Total Suspended Solids
- UF – Ultrafiltration

Appendix 4: Additional Information

We encourage you to learn more:

- Austin Onsite Water Reuse website https://www.austintexas.gov/department/onsite-water-reuse-systems
- California Water Boards – State Water Resources Control Board
https://www.waterboards.ca.gov/drinking_water/certlic/occupations/DWopcert.html
- Environmental Operators Certification Program Building Water Systems – New Certification
https://eocp.ca/operator-digest/building-water-systems-a-new-certification/
- EPA: Fact Sheets on Water Quality Parameters
https://www.epa.gov/awma/factsheets-water-quality-parameters
- National Blue Ribbon Commission Factsheet
https://watereuse.org/wp-content/uploads/2023/03/NBRC_Factsheet_2023_Final.pdf
- National Blue Ribbon Commission for Onsite Non-potable Water Systems website
www.watereuse.org/nbrc
- National Blue Ribbon Commission for Onsite Water Systems: 2024 NBRC Action Plan: Accelerating Onsite Water Systems in Communities
https://watereuse.org/wp-content/uploads/2024/07/FINAL2024NBRCACTIONPLAN.pdf
- National Blue Ribbon Commission for Onsite Non-potable Water Systems: Health Risk-based Benchmarks for Onsite Treatment of Water
https://watereuse.org/wp-content/uploads/2023/11/WWE_NBRCONWS_2023-09-13.pdf
- San Francisco Public Utilities Commission Onsite Water Recycling: An Innovative Approach to Solving an Old Problem/National Blue Ribbon Commission Onsite Water Reuse eBook
https://watereuse.org/wp-content/uploads/2023/11/OnsiteWaterTreatment_2022_v8.pdf
- San Francisco Public Utilities Commission Webinar: Insights from Operators of Onsite Non-potable Water Systems, May 1, 2023
https://youtu.be/H-9jSZZLxPI
- San Francisco Public Utilities Commission Webinar on Lessons Learned, October, 21, 2021
https://youtu.be/8xtvgaaErDw
- Required Levels of Backflow Protection for Onsite Water Reuse Systems, October 14, 2025
https://www.sfpuc.gov/sites/default/files/construction-and-contracts/design-guidelines/Req-Levels_BF-Protection_OSWR.pdf
- Resources for Onsite Non-Potable Water Programs – US Water Alliance:
https://uswateralliance.org/resources/resources-for-onsite-non-potable-water-programs/
- San Francisco Department of Public Health Website
https://www.sfdph.org/dph/EH/Water/nonPotable.asp
- San Francisco Public Utilities Commission website
www.sfpuc.org/npo
- San Francisco Public Utilities Commission Webinars: Part 1 and 2: Decoding the Log Reduction Targets
Part 1: https://youtu.be/r71avkw7eKM
Part 2: https://youtu.be/Q7LATbx83oc
- Title 40 of the Code of Federal Regulations (CFR), https://www.epa.gov/laws-regulations/regulations#cfr
- Part 503 (58 FR 9248-9415) – regulates all biosolids that are land applied, incinerated, or surface-disposed per the U.S. EPA [WWTF 1 Ch1 p32 para2]
- 40 CFR 258 – regulates sludge that is landfilled with other waste [WWTF 1 Ch1 p32 para2]
- IAPMO/ANSI Z1324 (Alternate Water Source Systems for Multi-Family and Commercial Use)
- ASSE/ARCSA/IAPMO/ANSI PQ 21000 (Rainwater Catchment Systems Personnel)

- IAPMO/ASSE/ANSI PQ 10000 (Green Plumbing Systems Installers)
- NSF/ANSI 350 (Water Reuse Systems Certificate)
- ARCSA/ASPE/ANSI Standard 63 Rainwater Catchment Systems
- ARCSA/ASPE/ANSI Standard 78 Stormwater Harvesting System Design for Direct End-Use Applications

Appendix 5: Answer Key for Test Your Knowledge Questions

Section 1: Introduction to Onsite Non-potable Water Treatment

1. True or False. The health risk-based framework relies on end-point coliform monitoring to determine whether water is suitable for reuse.

   A. True

   B. False

2. What is the multiple barrier concept?

   A. Maintaining a disinfectant residual to protect against opportunistic pathogens

   B. Use of multiple treatment processes to help provide safe water for reuse and increase reliability

   C. Use of multiple types of alternate water sources in an ONWS

   D. A physical process to clear suspended solids from water

   E. Reverse osmosis concentrate

3. What is the primary purpose of pretreatment in an ONWS treatment train?

   A. Remove coarse materials/solids prior to downstream treatment processes

   B. Equalize the supply of source water and demand for non-potable water

   C. Disinfect the water for reuse

   D. Store the water for reuse

4. Which building type is not a focus of the handbook?

   A. Commercial

   B. Mixed use

   C. Residential

   D. Multifamily

5. Which unit process is considered the essential workhorse for treating blackwater and graywater?

   A. Flow equalization

   B. Filtration

   C. Biological treatment

D. Pretreatment

Section 2: Roles and Responsibilities

1. Which of the following are typical responsibilities of an operator of an ONWS? (Select all that apply.)

   A. Operates and maintains the ONWS to ensure that all treatment goals are met

   B. Issues permits, reviews, and reviews design plans for the ONWS

   C. Is responsible for designing the ONWS

   D. Maintains communication between stakeholders

2. True or False. The ONWS operator should develop a sampling plan that defines the frequency, location, type of sample, analytical methods, contact information for the lab conducting the analyses, and any other necessary information (e.g., holding times, turnaround times).

   A. **True**

   B. False

3. Under what conditions are automated ONWS alarms set to notify the operator?

   A. Lunch time

   B. Response to critical malfunction

   C. Update to the organizational chart for the ONWS team

   D. When a toilet is flushed using non-potable water

4. What is the system owner responsible for? (Select all that apply.)

   A. Writes the operations and maintenance plan for operating the ONWS

   B. Permit compliance

   C. Assembling the ONWS team

   D. **Hiring and managing staff**

5. The Regulator does not perform which of the following functions?

   A. Reviews plans

   B. Permits systems

   C. Routine maintenance

   D. Reviews the compliance report

Section 3: Applicable Regulations/Codes

1. What is an operations plan?

   A. A document with written details on the current operation, maintenance, and management procedures for operating the ONWS

   B. A permit that provides authorization for the distribution and use of the non-potable water

   C. A document that is used to record all water quality sampling results

   D. A document that is used to obtain a building permit from the local jurisdiction

2. When does commissioning occur?

   A. During the design of the ONWS

   B. During the system construction inspection with the local jurisdiction

   C. Before the cross-connection test

   D. After the project start-up, when the fully functioning ONWS is tested

3. During commissioning, a regulator may inspect the ONWS to confirm it was installed in accordance with the design documents. They may verify the following: (Select all that apply.)

   A. Installation of the correct treatment process equipment

   B. Use of specific chemicals

   C. The use of drinking water fountains onsite

   D. The percent occupancy of the building

4. True or False. The operator should ignore any enforcement actions if a permit violation occurs.

   A. True

   B. False

5. Which stage is not typically found during project start-up?

   A. Confirm proper installation

   B. Confirm proper calibration

   C. Confirm water savings

   D. Confirm system function

Section 4: Risk-based Log Reduction Targets and Pathogen Crediting

1. What are the enteric pathogens of most significant concern in ONWS? (Select all that apply.)

   A. Fungi

   B. Bacteria

   C. Protozoa

   D. Viruses

2. What is the risk-based framework?

   A. A list of allowable non-potable end uses

   B. Identifies a health benchmark, such as an acceptable level of infections in a population, and uses that benchmark to calculate a level of treatment needed to achieve the goal

   C. Use of multiple treatment processes to help provide safe water for reuse and increase reliability

   D. The destruction or inactivation of pathogenic microorganisms by exposure to a chemical agent or physical process

3. How is the quality of rainwater generally described?

   A. Highly variable; influenced by land use, rainfall intensity, and surface conditions; generally lower quality than treated water

   B. Contains a high concentration of organic matter, pathogens, and nutrients, making it the most contaminated of the alternate water sources

   C. Generally of higher purity compared to other alternate water sources, but can contain various impurities washed off roof surfaces

   D. Variables are based on household products and activities; may contain soap, detergents, hair, body oils, food particles, and minor pathogens

4. LRT is an acronym for which of the following phrases?

   A. Log Reduction Target

   B. Long Reach Chain

   C. Log Reaction Time

   D. Long Range Target

5. The de facto benchmark for annual risk of infection used to create Log Reduction Targets is which of the following?

   A. 1 in 10 annual risk of infection

   B. 1 in 5,000 annual risk of infection

   C. 1 in 10,000 annual risk of infection

   D. 1 in 100,000 annual risk of infection

Section 5: Flow Equalization and Pretreatment

1. What is the purpose of flow equalization in an ONWS treatment train?

   A. Collect the initial runoff from a building's roof

   B. Help balance variable fluctuations in both flow and quality that are challenging for the treatment processes

   C. Process to screen large solids and debris

   D. Monitor the quality of the incoming source water in real time

2. True or False. If an ONWS experiences variability in both influent flow and treated water demand, flow equalization should only be considered at the beginning of the treatment train.

   A. True

   B. **False**

3. Which is not considered a pretreatment screen?

   A. Course screen

   B. Vortex filter

   C. Fine screen

   D. First flush divertor

4. Which of the following are key tasks to ensure efficient operation of a grinder pump? (Select all that apply.)

   A. Ensuring there is a backup power supply to keep the pump operational during outages

   B. Regular inspections for signs of wear or damage

   C. Keeping the pump clear of debris and obstructions

   D. Having the pump serviced every three to five years, or as recommended by the manufacturer

5. What can an operator do to prevent non-flushable items from clogging the ONWS?

   A. Work with building management to educate occupants about what shouldn't go down the drain

   B. Encourage occupants to flush wipes down the toilet

   C. Increase the volume of potable makeup water

   D. Purchase a new hose

Section 6: Biological Treatment (all advanced content)

1. True or False. MBRs can take weeks or months to establish a stable population of microorganisms needed to meet treatment standards and complete commissioning.

   A. True

   B. False

2. Why is biological treatment used in an ONWS treatment train? (Select all that apply.)

   A. Increase operational reliability of downstream treatment processes

   B. Minimize color and odor issues

   C. To create hydraulic conditions to separate solids from the water

   D. Improve the reliability of pathogen reduction performance in downstream processes such as UV, chlorine, or ozone disinfection

3. What is the target level for biological oxygen demand (BOD) in the EPA's Guidelines for Water Reuse?

   A. ≤ 2 mg/L

   B. 0 mg/L

   C. ≤ 10 mg/L

   D. ≤ 1 mg/L

4. Why is it important to keep total suspended solids (TSS) levels low?

   A. It is a cost-saving measure

   B. To prevent irrigation pipes from clogging

   C. High TSS levels can lead to membrane fouling, reducing the efficiency of the filtration process

   D. To control the amount of chemicals used

5. Biological treatment systems include all but the following.

   A. Membrane bioreactor

   B. Engineered wetlands

   C. Vortex filter

   D. Fixed bed bioreactor

Section 7: Filtration

1. What is the primary purpose of filtration?

   A. Minimize growth of opportunistic pathogens

   B. Remove particulates that may shield pathogens from effective disinfection downstream

   C. Inject air into a tank

   D. Help the operator keep track of inspections

2. What is one key consideration when maintaining bag filters?

   A. The level of water in the storage tank

   B. Filter placement

   C. Use an analyzer that can accurately measure both free chlorine and total chlorine

   D. Keep an eye on the pressure differential across the filter; a significant increase indicates the filter needs cleaning or replacement

3. Typical filtration treatment technologies include all but the following?

   A. Bag filter

   B. Media filtration

   C. Engineered wetland

   D. Reverse osmosis

4. To receive pathogen crediting for the use of a reverse osmosis, what surrogate parameter needs to be continuously monitored?

   A. BOD

   B. Electrical conductivity

   C. Flow

   D. Potable makeup water

5. Why do you perform a pressure differential test on membranes? (Select all that apply.)

   A. To test automated control systems and alarm functions

   B. Encourage membrane fouling and poor performance

   C. A high-pressure differential across a membrane indicates fouling or scaling, which reduces water flow and efficiency

   D. A significant pressure differential across filters, such as bag or cartridge filters, suggests clogging and means that cleaning or replacement of the filters is needed

Section 8: Disinfection

1. What are the typical forms of disinfection used in ONWS? (Select all that apply.)
   A. Chlorine
   B. Membrane bioreactor
   C. Ultraviolet light
   D. Ozone
2. What is an advantage of using free chlorine vs chloramines?
   A. It effectively eliminates a wide range of pathogens quickly
   B. It is more stable and provides longer-lasting disinfection
   C. It produces fewer by-products
   D. It is less likely to react with organic matter
3. What is the purpose of secondary disinfection?
   A. Prevents accidental chemical spills
   B. Limits the growth of viruses
   C. Protects against opportunistic pathogens
   D. Minimize particulates in the water
4. What is not a typical UV validation parameter?
   A. UV intensity
   B. Flow Rate
   C. UV energy consumption
   D. UV transmittance
5. When is breakpoint chlorination used?
   A. To ensure chemical containers are tightly sealed to prevent leaks and evaporation
   B. When ammonia is present in the treated water
   C. Validation testing of the chlorine contactor
   D. Slow the flow of water through the chlorine contactor
6. What are the considerations for handling ozone safely? (Select all that apply.)
   A. Keep ambient ozone concentrations above 0.1 mg/L
   B. Ignore building and fire codes
   C. Generate more ozone
   D. Monitor for ambient ozone

Section 9: Monitoring Water Quality and Physical Parameters

1. What does a grab sample tell the operator?

    A. An average representation of grab samples taken at different times or locations and pooled together to create one sample

    B. An average representation of all water quality exceedances

    C. A water level measurement using ultrasonic waves

    D. A snapshot of the quality of the water at the exact time and place where the sample was taken

2. What is a sample hold time?

    A. A process for maintaining accurate and reliable readings in continuous monitoring instruments

    B. The length of time allowed between when a sample is collected and when it is analyzed

    C. A method of detecting microbial contamination

    D. A measure of water clarity

3. What are examples of common sensors used for continuous monitoring in ONWS? (Select all that apply.)

    A. Chlorine residual meter

    B. Turbidimeter

    C. Online pH meter

    D. **Flow meter**

4. How do UV intensity sensors work?

    A. Measure the intensity of UV light within the reactor, which can be used to adjust the UV dose in real time

    B. Measure the clarity of the water using a turbidimeter

    C. Measure using monitoring sensors to ensure sufficient aeration for the microbes to consume the biochemical oxygen demand

    D. Monitor the percentage of UV light that passes through a water sample, indicating how clear the water is and assessing the efficiency of UV disinfection

5. Using biological treatment in graywater and blackwater systems helps to reduce BOD, thereby providing the following benefits: (Select all that apply.)

    A. Improves the performance of downstream filtration systems

    B. Decreases the risk of sedimentation in storage tanks and distribution systems

    C. Providing a cost-effective way to measure bacterial growth

    D. **Results in clearer water with less visible particles, enhancing the overall water quality for non-potable applications**

6. **Calculating Wasting Rates.**

An ONWS uses a Membrane Bioreactor (MBR) to treat wastewater. The system contains 140 lbs of MLSS in the aeration tank. The operator wants to maintain a Solids Retention Time (SRT) of 15 days.

Using the formula provided below, what is the required daily wasting rate?

A. 6.5 lbs/day

B. 8.0 lbs/day

C. 9.3 lbs/day

D. 10.5 lbs/day

Using the formula:

Wasting Rate (lbs/day) = $\frac{\text{Total MLSS (Lbs)}}{Target\ SRT\ (days)}$

7. **Calculating F/M Ratio**

A small ONWS treats **30,000 gallons per day (GPD)** of wastewater. The **influent CBOD concentration** is **10 mg/L**.

The **aeration tank volume** is **15,000 gallons**, and the **MLVSS concentration** is **3,800 mg/L**. Using the formula provided below, what is the F/M Ratio?

A. 0.12

B. 0.07

C. 0.24

D. 0.31

Using the formula:

F (Food) = Flow (MGD) × CBOD × 8.34

M (Microorganisms) = Aeration Volume (MG) × MLVSS × 8.34

F/M Ratio = F ÷ M

8. **Calculating Solids Retention Time (SRT)**

A small water reuse facility has 100 lbs of MLVSS in its aeration system. The system wastes 8 lbs of MLSS per day. Using the formula provided below, what is the Solids Retention Time (SRT)?

A. 10.3 days

B. **12.5 days**

C. 15.9 days

D. 18.0 days

Using the formula:

SRT (days)= $\frac{\text{Total MLSS (lbs)}}{\text{MLSS Wasted lbs/Day}}$

Section 10: Chemical Storage, Handling, and Feeding

1. What is the rule of thumb for sizing chemical storage?

    A. Provide enough for six months of operation

    B. Provide enough for three times the volume of the largest expected delivery and enough for 1 month of operation

    C. Provide 1.5 times the volume of the largest expected delivery and enough for 2 weeks of operation

    D. Provide enough for three months of operation

2. When chemicals are stored and handled onsite and where an operator may be exposed, what safety measures should be in place? (Select all that apply.)

    A. Presence of an aerator

    B. Spill containment

    C. Chemical sumps and pumps

    D. Emergency shower and eye wash stations

3. True or False. Shower and eyewash stations should be reachable within 10 seconds because immediate response to chemical exposure is vital.

    A. True

    B. False

4. Underdosing of chemicals can lead to what issue?

    A. Pathogens may not be adequately inactivated or destroyed

    B. Pump failure

    C. Reduced UV Transmittance

    D. Increased confidence in system operability

5. Because an accurate measurement of chemicals being added is crucial, what is one strategy an operator can use to prevent under- or over-dosing?

    A. Use the critical control point framework to reduce and prevent hazards

    B. Utilize automated dosing systems can enhance accuracy and consistency in chemical addition

C. Establish diversion setpoints to redirect flow to the sewer

D. Perform a challenge test with an appropriate surrogate parameter

6. Calculating Stock Concentration

A small water reuse system operator needs to achieve a chlorine dose of 0.5mg/L in 15,000 liters of treated water. The available disinfectant is 12.5% sodium hypochlorite (which is 125,000 mg/L as a stock solution).

Using the formula provided below, determine the number of liters and gallons of 12.5% hypochlorite solution required (1 gallon = 3.785 liters).

A. 0.15 L (0.57 gal)

B. 0.06 L (0.23 gal)

C. 0.75 L (0.20 gal)

D. 1.00 L (0.26 gal)

Using the formula:

Volume of Stock Solution (L) = $\frac{Desired\ Dose\ \left(\frac{mg}{l}\right)\ x\ Volume\ of\ Water\ (l)}{\text{Stock Solution concentration }(\frac{\text{mg}}{\text{l}})}$

(1 gallon = 3.785 liters)

7. Calculating Chemical Dose and Feed Rate

A water reuse system operator needs to dose 0.6 mg/L of chlorine into a flow of 0.25 MGD using a 12.5% sodium hypochlorite solution (which is 125,000 mg/L).

Using the formula provided below, what is the required chemical feed rate?

A. 3.78 L/day

B. 5.67 L/day

C. 4.54 L/day

D. 9.46 L/day

Using the formula:

Chemical Feed Rate (L/day) = $\frac{\text{Desired Dose }\left(\frac{\text{mg}}{\text{l}}\right) x\ Flow\ Rate\ (MGD) x\ 3.785\ x\ 10^6}{2aChemical\ concentratiuon\ (\frac{mg}{l})}$

Section 11: Process Control and Online Monitoring

1. What is the critical control point framework?

    A. A real-time monitoring system to help operators adjust chemical dosages dynamically

    B. A framework of critical parameters that, if not met, causes the system to shut down or divert to drain

    C. A safety plan for preventing chemical leaks and spills

    D. A maintenance plan for maintaining a UV reactor

2. pH sensors and analyzers should be used to monitor and keep pH levels in what range?

    A. 5.5-6.5

    B. 8.5-10

    C. 6.5-8.5

    D. 4.5-5.5

3. What is the appropriate response for an ONWS when critical parameters are out of range?

    A. Keep operating as usual

    B. Spill excessive water on the floor

    C. Shut down all pumps to send water to the toilets

    D. Automated diversion to sewer

4. True or False. Online monitoring and telemetry give operators intermittent access to information that allows them to analyze water quality and system performance data only upon request.

    A. True

    B. False

5. What is the calibration procedure for a DO sensor?

    A. Use a zero-oxygen solution and a saturated oxygen solution to calibrate the sensor. Adjust the sensor readings to match the known oxygen levels

    B. Use a calibrated thermometer to verify the accuracy of the sensor

    C. Verify the dosing rate by measuring the volume of chemical dispensed over a set period

    D. Use standard turbidity solutions to verify the accuracy of the sensor

Section 12: Standard Operating Procedures

1. True or False. SOPs are the same as the operations plan.

    A. True

    B. False

2. What are standard operating procedures (SOPs)?

    A. Detailed plan for bringing the ONWS into normal working conditions

    B. A list of all confined spaces and classifications based on hazard level

    C. A map showing the locations of all chemical spill kits

    D. Step-by-step instructions were developed to help operators execute complex or routine operations of specific equipment

    E. A method to collect historical data on ONWS performance

3. Why are SOPs useful? (Select all that apply.)

    A. Ensure tasks are performed consistently and in compliance with rules

    B. Help minimize confusion

    C. Require operators to work overtime

    D. Increase maintenance responsibilities for the operator

4. SOPs are usually developed by the following members of the ONWS team: (Select all that apply.)

    A. Regulator

    B. Building occupants

    C. Operator

    D. Design engineer

5. Changes to SOPs typically occur for which of the following reasons?

    A. New equipment

    B. Maintenance changes

    C. New regulations

    D. All of the above

Section 13: Basics of Collection, Distribution, and Storage

1. What functions do pumps provide in an ONWS? (Select all that apply.)

   A. Move water through the collection system

   B. Move treated water from the storage tank to end uses (e.g., toilets)

   C. Meter chemicals into tanks or processes

   D. Increase the elevation of water in a tank or distribution box so it can flow by gravity to downstream processes

2. What are the advantages of using an electronically actuated valve?

   A. Reliable sealing and low pressure drop when fully open

   B. Versatile flow control and easy to switch between different flow paths

   C. Precise control, integration with control systems, and reduced manual intervention

   D. No moving parts and minimal maintenance

3. Why is backflow protection important in ONWS?

   A. Prevents mosquitoes from entering the collection tank

   B. Protects non-potable water from entering the potable water distribution system

   C. Controls odors from the wastewater treatment

   D. Prevents tank leaks

4. True or False. Cleaning ONWS storage tanks is a common and frequent task, typically performed monthly.

   A. False

   B. True

5. All but the following are typical flow meters.

   A. Ultrasonic

   B. Mechanical

   C. Vortex

   D. Haptic

Section 14: Safety Considerations for Operators

1. What is an environment, health, and safety plan?

   A. Detailed plan for start-ups and shutdowns of the ONWS

   B. Describes the staffing needs for operating the ONWS

   C. Lists the critical control parameters and response conditions

   D. Ensures compliance with OSHA regulations and creates procedures for identifying workplace hazards and reducing accidents and exposure to harmful situations

2. Examples of information included in a chemical safety plan include the following: (Select all that apply.)

   A. Turbidimeter calibration procedures

   B. Identification of appropriate PPE

   C. Inventory of hazardous substances

   D. Information on non-flushable items

3. What should an operator be aware of when working in confined spaces? (Select all that apply.)

   A. Confined space hazards

   B. Car alarm sounds

   C. Entry procedures

   D. Emergency response

4. Which of the following does not need to be included in chemical safety records?

   A. Weekly hazardous material inspection logs

   B. Chemical release assessment and reporting records

   C. Design of the ONWS disinfection system

   D. Hazardous waste manifests

5. The acronym SDS refers to which of the following terms?

   A. Site Detail Survey

   B. Safety Data Sheet

   C. Sorted Department Site

   D. Semi Divided Substructure

Section 15: Operational Considerations to Maintain Aesthetics of Treated Water

1. Color of the treated water can be an issue with what types of ONWS that have higher organic concentrations? (Select all that apply.)

   A. Graywater

   B. Stormwater

   C. Condensate

   D. Blackwater

2. Which of the following treatment processes can be used to remove color effectively? (Select all that apply.)

   A. Biological treatment

   B. Disinfection

   C. Filtration

   D. Aeration

3. True or False. Reverse osmosis systems can effectively control for odor and color.

   A. **True**

   B. False

4. How do granular activated carbon (GAC) systems work?

   A. Use semipermeable membranes to remove contaminants from the water

   B. Use high pressure to remove contaminants from the water

   C. Use activated carbon granules to adsorb contaminants from the water

   D. Use gravity to remove contaminants from the water

5. How often do GAC media need to be replaced?

   A. Never

   B. Twice a year

   C. Every two years

   D. Regularly

Section 16: Commissioning and Shutdown/Startups

1. A commissioning plan helps operators in the following ways: (Select all that apply.)

   A. Provide locations of all chemical spill kits

   B. Provide direction on how to replace a lamp in a UV reactor

   C. Provide clear procedures for restarting the ONWS

   D. Identify risks to water quality and water safety prior to occupying the building

2. Startup and commissioning are the processes of preparing the ONWS for what?

   A. To go on standby

   B. To operate to meet regulatory requirements and design specifications

   C. To recirculate

   D. To divert to the sewer

3. During system commissioning, what is not an example of an activity performed during plumbing checks? (Select all that apply.)

   A. Presence of irrigation hose bibs

   B. Backflow prevention device checks

   C. Cross-connection test

   D. Temperature of the faucet water

4. True or False. During commissioning, treated blackwater and graywater systems can immediately use the water in the building and are not required to divert it to the sewer.

   A. True

   B. **False**

5. Sources of plant seed material include all but the following sources.

   A. Activated sludge

   B. Commercial microbial inoculants

   C. Topsoil

   D. Healthy effluent