Guidelines for Source Water Control Options and the Impact of Selected Strategies on Direct Potable Reuse

by:

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2017

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<tr>
<td>AOP</td>
<td>Advanced Oxidation Potential</td>
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<td>ATP</td>
<td>Advanced Treatment Processes</td>
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<td>ATSDR</td>
<td>Agency for Toxic Substances and Disease</td>
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<td>AWP</td>
<td>Advanced Water Purification</td>
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<td>BES</td>
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<td>BMP</td>
<td>Best Management Practice</td>
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<td>BNR</td>
<td>Biological Nutrient Removal</td>
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<td>Biochemical Oxygen Demand</td>
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<td>C4P</td>
<td>Countywide Pollution Prevention Partnership Program</td>
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<td>Cd</td>
<td>Cadmium</td>
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<td>CDNB</td>
<td>Chloro-2, 4-Dinitrobenzene</td>
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<td>Commonwealth Science and Industry Organization</td>
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<td>DEET</td>
<td>N,N-Diethyl-Meta-Toluamide</td>
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<td>DNP</td>
<td>2, 4-Dinitrophenol</td>
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<td>DO</td>
<td>Dissolved Oxygen</td>
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<td>DOC</td>
<td>Dissolved Organic Carbon</td>
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<td>DPR</td>
<td>Direct Potable Reuse</td>
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<td>DSS</td>
<td>Decision Support System</td>
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<td>DWEL</td>
<td>Drinking Water Equivalent Level</td>
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<td>EDKB</td>
<td>Endocrine Disrupter Knowledge Base</td>
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<td>EPS</td>
<td>Extracellular Polymeric Substances</td>
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<td>EQ</td>
<td>Equalization Basin</td>
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<td>FAO</td>
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<tr>
<td>FOG</td>
<td>Fats, Oil, And Grease</td>
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<td>FTA</td>
<td>Fault Tree Analysis</td>
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<td>GAC</td>
<td>Granular Activated Carbon</td>
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<td>LASAN</td>
<td>Los Angeles Sanitary District</td>
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<tr>
<td>MBR</td>
<td>Membrane Biological Reactors</td>
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<tr>
<td>MF</td>
<td>Microfiltration</td>
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<tr>
<td>mg/L</td>
<td>Milligrams Per Liter</td>
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<tr>
<td>MLE</td>
<td>Modified Ludzack-Ettinger</td>
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<td>MLSS</td>
<td>Mixed Liquor Suspended Solids</td>
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<td>MRTD</td>
<td>Maximum Recommended Therapeutic Dose</td>
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<td>ORP</td>
<td>Oxygen Reduction Potential</td>
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<td>PAC</td>
<td>Powdered Activated Carbon</td>
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<td>PC</td>
<td>Positive Control</td>
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PhACs  Pharmaceutically-Active Compounds
POCs
RA  Reservoir Augmentation
RBCs  Rotating Biological Contactors
RO  Reverse Osmosis
sAOR  Specific Ammonium Oxidation Rate
SBR  Sequential Batch Reactor
SCWO  Supercritical Water Oxidation
SME  Subject Matter Expert
sOOUR  Specific Oxygen Uptake Rate
SRT  Solids Retention Time
SVI  Sludge Volume Index
SWRCB  State Water Resources Control Board
SWTF  Source Water Treatment Facility
SWTR  Surface Water Treatment Rule
TN  Total Nitrogen
TOC  Total Organic Carbon
TSS  Total Suspended Solids
TTO  Total Toxic Organics
UEW  Upset Early Warning System
UF  Ultrafiltration
USDHHS  United States Department of Health And Human Services
USEPA  United States Environmental Protection Agency
USFDA  United States Food and Drug Administration
UV  Ultraviolet
WBWD  West Basin Water District
WEF  Water Environment Federation
WERF  Water Environment Research Foundation
WE&RF  Water Environment & Reuse Foundation
WHO  World Health Organization
WRRF  Water Resource Recovery Facility
WTP  Water Treatment Plant (Potable)
WWTP  Wastewater Treatment Plant
Executive Summary

Project Background/Objectives

Utilities which own and operate existing wastewater treatment infrastructures (collection, treatment and disposal) may consider expanding these to include advanced water purification facilities (AWPFs). Alternatively, they may consider collaborating with other entities who currently operate water treatment facilities and distribution. The governing paradigms, treatment objectives, operational objectives and indeed vernacular for wastewater treatment facilities and operators have historically been different to those of water treatment facilities and operators. However, in the development of a successful potable reuse program it may be highly beneficial to overcome these inherent differences. This integration will enable the two programs (collection/wastewater treatment and water treatment/distribution) to effectively collaborate and complement each other to provide a safe, reliable supply of potable reuse water. This guidance document was developed as part of a broader WE&RF/California Potable Reuse effort to address critical questions to achieve this overarching goal. The primary objectives of this guidance document are to:

- Evaluate upstream wastewater treatment impacts (e.g. biological treatment through N/dN-nitrification/denitrification and other means, chemical treatment, industrial source control) on DPR source water quality and DPR processes
- Evaluate impact of hydraulic control mechanisms (e.g. flow equalization and source water storage buffers) on influent water quality and flow variations that “stress” the DPR process

Project Approach

The project consists of the three integrated components described below.

1. Literature Compendium

The Literature Compendium (Compendium) is a broad literature review on subjects related to links between source control in the collection system, wastewater processes operation and performance, and operations and performance of potable reuse treatment systems. The Compendium is published as a standalone document and available electronically via the WE&RF website at XXXXX.

2. Utility Case Studies

A comprehensive summary of the design, operation and performance of the wastewater treatment facilities and advanced water purification facilities at each of the four participating utilities are included in the Case Studies. Going beyond (or more aptly upstream) of the wastewater and AWPF design, operation and performance, these case studies provide important insights into the collection system management and source control programs implemented at each of the four utilities. An overview of each of the utility systems is provided in Table ES-1. Readers will find this information extremely beneficial, perhaps even using it as a set of templates from which to selectively pick and choose those strategies and approaches most beneficial and applicable to specific systems under consideration. The Case Studies are also published independently on the WE&RF website but are a critical part of this Guideline document in that the lessons learned from each of the utilities has provided significant input to the findings in this Guideline. The Case Studies can be found at XXXXX.
3. Guidelines for Source Control and Source Water Treatment Facility Design and Operation

The Guideline (i.e., this document) is a culmination of the efforts of this project motivated by the findings in developing the Compendium and the Case Studies. The authors gave careful thought and considerations to integrate the treatment of the wastewater and advanced purification facilities. As noted previously, the water and wastewater treatment communities though inexorably linked have for some time now been working somewhat in two separate silos. This has resulted in a set of terminology consistently applied within one community but not the other. However, potable reuse presents a potentially new challenge – all systems may be managed by the same set of professionals. Therefore, a common and harmonized vernacular is needed. To aid in this effort, the terminology noted below to describe the systems in an integrated potable water reuse paradigm. These are highlighted here as they may not currently be part of the vocabulary of the unified Water and Environment community of professionals.

Source Water

Water contained in the collection system which will eventually serve as the source for the potable reuse processes. This may have been, or continue to be, called sewage or influent. We elected to use the term Source Water to convey that it should be effectively managed as an important resource. This should enable utilities to elevate the importance of source control and/or pollution prevention programs.

Integrated Resource Recovery Facility (IRRF)

A resource recovery facility which, in addition to functioning as a WRRF (as defined by WEF) – integrates potable reuse through an advanced water purification facility (AWPF). We elected to use the acronym IRRF to differentiate these utilities from WRRFs specifically because of the AWPF element. Thus, there must be an emphasis on integrated staff training (on both water and wastewater treatment process) and integrated system management to ensure a reliable and consistent production of supply water (see below) to the AWPF.

Source Water Treatment Facility (SWTF)

A Source Water Treatment Facility (SWTF) is a relatively new term which is the collection of unit operations which together treat the source water and produce a supply water (see below) for the AWPF. Historically, this may be referred to as a wastewater treatment plant/facility or water resource recovery facility. We elected to use the acronym SWTF to emphasize the fact that these processes must now be managed to treat a source water and consistently produce a supply water. These terms are used interchangeably in this document.

Supply Water

Water produced by a SWTF which may be further treated in an AWPF. Note that both the WRRF and AWPF can be within the same fence line and managed by a single entity or be separate entities. We elected to use the term Supply Water to emphasize that WRRFs are responsible for more than an effluent – indeed they are supplying water to the AWPF to meet a community’s thirst for reliable and sustainable potable water.
These guidelines are intended to provide a framework for consideration when integrating effective source control with source water treatment and AWPF processes.

Table ES-1  Overview of Case Study Participant Facilities

<table>
<thead>
<tr>
<th>CASE STUDY</th>
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| Case Study 1: OCSD and OCWD      | **Source Water for IPR: Combination trickling filter & air activated sludge secondary effluent.** OCSD currently provides secondary effluent for treatment at OCWD’s AWPF, consisting of MF-RO-UV AOP, to produce IPR quality water.  
1. Extensive and established source control program for IPR applications  
2. OCSD provides OCWD’s AWPF with secondary effluent from a combination of:  
   - Trickling Filters (non-nitrified, maintains ammonia for chloramines formation)  
   - Air Activated Sludge 1 and Air Activated Sludge 2  
3. Addition of two, 7.5 MG, secondary effluent flow equalization tanks to minimize diurnal flow impacts on AWPF  
4. Source water for IPR treatment system is made up of 75:25 blend of nitrified to non-nitrified secondary effluent  
5. AWPF performance impacted by diurnal flow variations and secondary effluent quality (e.g. turndown of RO units by nearly 50% and maintaining consistency in post-treatment stabilization) |
| Case Study 2: City of Los Angeles Bureau of Sanitation and West Basin MWD | **Source Water for IPR: Pure oxygen activated sludge process.** The Hyperion Treatment Plant produces secondary effluent through a pure oxygen activated sludge process, majority of which is discharged into the Pacific Ocean  
1. Pure oxygen activated sludge process is provided at Hyperion  
2. Secondary effluent is pumped to West Basin’s ECLWRF  
3. Quality of secondary effluent has significantly declined over the years, impacting design capacity and treatment efficiency (e.g. increased ammonia levels have stressed BIOFOR units and increased organic content has resulted in higher biofouling potential for membrane processes)  
4. West Basin has a wide range of reuse treatment technologies to produce the five tertiary treated recycled water qualities, including the new addition of ozone to the IPR treatment train (Ozone-MF-RO-UV AOP). |
| Case Study 3: City of San Diego | **Source Water for IPR: Tertiary Effluent.** The North City Water Reclamation Plant is operated as a scalping plant that currently produces tertiary quality effluent for non-potable reuse  
1. No returns flows within North City Water Reclamation Plant  
2. Primary treatment system designed to handle flow variations  
3. Primary effluent flow equalization (2.4 MG) is provided at the North City Water Reclamation Plant  
4. Full nitrification and partial denitrification secondary activated sludge process with clarification is provided upstream of tertiary process  
5. Tertiary effluent is fed to AWPF demonstration facility (1mgd), located on-site |
| Case Study 4: Singapore PUB       | **Source Water for IPR: Step-feed activated sludge secondary effluent and MBR filtrate blend.** The conventional activated sludge process at Changi Water Reclamation Plant (CWMP) was partially retrofitted with MBR. The Changi NEWater Plant (CNP) receives the blended filtrate/secondary effluent to produce IPR quality water (branded NEWater).  
1. Extensive and established source control program of feed to CWMP  
2. CWMP secondary treatment (800 MLD) partially retrofitted with MBR (60 MLD) to enhance IPR treatment feed water quality.  
3. CNP employs MF-RO-UV to produce IPR quality water (228 MLD) |
Summary of the Guidelines

Integration of DPR into IRRF

What does the integration of DPR into an overall Integrated Reuse Recovery Facility (IRRF) look like? Chapter 2 addresses these issues and Figure ES-1 illustrates such an example. The IRRF receives source water from a municipal wastewater collection system (Source Water) and is comprised of a Source Water Treatment Facility (SWTF) and an Advanced Water Purification Facility (AWPF). The SWTF provides the feed (or DPR Supply Water) to the AWPF. The purified water from the AWPF can then be used in several different DPR blending scenarios including:

1) WTP raw water supply,
2) WTP raw water storage reservoir, and
3) WTP distribution system.

Here, the purified water used for DPR would be one of several possible resources that could be recovered from the source water or SWTF. Other examples (not shown) might include energy and fertilizer from solids digesters used in the SWTF, and protein recovery from the source water.

Figure ES-1 Illustration of an IRRF incorporating DPR
The AWPF consists of several advanced water treatment processes to provide a multiple barrier approach to chemical and pathogen contaminant removal. Several alternative DPR treatment trains can be utilized to meet the purification requirements as depicted in Figures ES-3 and ES-4. A review of the impact that the quality and flow variation of the DPR supply water can have on the design and operation of the AWPF processes as well as mitigation and design considerations to maximize efficiency and performance was based in part on the information supplied by the participating utilities and data from the literature.

Two example DPR Treatment trains are highlighted and for each treatment train, a table outlining the AWPF process, the process function, key design factors and key DPR supply water constituents that impact the design and operation of the treatment trains are covered in detailed tables. (Equalization storage could be supplied ahead of the MF/UF to simplify membrane operation.) The overall findings show poor source water quality and/or wide flow variations can have significant impact on the AWPF process design and operations. Such impacts translate to increased capital and O&M costs of the AWPF process.
Source Control Strategies for DPR

Source control issues are discussed from a variety of different perspectives in Chapter 3. Source control is a critical element for wastewater treatment and for any potable reuse program, regardless of whether it is IPR or DPR. Source control is a combination of managerial and operations barriers that are implemented as part of a multi-barrier approach to eliminate or control the discharge of pollutants to wastewater that may be difficult to treat, impact maintenance and operations, potentially impact public or environmental health, and/or may impair the final quality of the treated water intended for DPR (APAI, 2105; Tchobanoglous et al., 2015). Source control issues looked at how to:

- Establish the differences between “pretreatment” programs and “source control” programs,
- Develop the key elements of source control programs for DPR,
- Understand the effectiveness of source control, and
- Determine how a source control program may or may not differ from a program implemented for an indirect potable reuse (IPR) project.

It was pointed out that source control is in the eye of the beholder and that as a utility embarks on establishing their program they should fully understand the interrelationships and differences between conventional pretreatment programs and source control. A detailed table describes the key program elements of a pretreatment program and the resources that can be utilized to develop each of those elements.

One of the key elements that differentiates a pretreatment program from source controls is a shift in focus from meeting discharge limits (pretreatment programs) and becoming part of an integrated water supply program (source control.) A detailed table identifies 14 program elements and thoroughly describes the formation and structure of those elements.

Some examples of international source control programs are provided as a resource. The chapter also identifies thirteen (13) key elements to consider in the development of source control program and strategies for DPR. Examples of potential sources of select compounds of emerging concern (CECs) that can impact the downstream SWTFs were also provided.

Source Water Treatment Facility Design, Operations and Optimization for Potable Reuse

Chapter 4 provides the reader with guidance related to the configuration, process design and operation of a SWTF compatible with AWP for potable reuse. SWTFs have been historically designed and operated to achieve a high-quality effluent suitable for environmental discharge. Such end-point targets are readily achieved with a wide range of secondary and tertiary treatment alternatives. However, integration of an AWPF in the scheme requires a paradigm shift in the operation of SWTFs because the treated effluent is the supply water for the AWPF. Several principal objectives were identified for SWTFs expanding to integrate AWP were identified and discussed. Some of the principal objectives for SWTFs expanding to integrate AWP include:

- Production of a consistently high quality supply water suitable for further treatment in the AWPF.
- Ability to detect poor-quality supply water and divert flow away from the AWP process.
- Produce steady consistent flow
The chapter also focuses the provision of guidance related to the configuration, process design and operation of a SWTF compatible with AWP for potable reuse. The focus of the Guideline involved the following four elements:

1) Nitrogen Management  
2) Flow and Load Variation Management  
3) Management of CECs  
4) Sidestream Management  

A variety of tables are developed to assist utilities and their consultants on facility design, operations and the optimization of the systems to achieve potable reuse. These tables included:

- Table 4.1 Summary of desired supply water effluent characteristics for potable reuse AWP processes  
- Table 4.2 Guidance for designers and operators to manage the principal factors which influence nitrogen management efficiency  
- Table 4.3 Management Strategies for Sidestreams  

**Source Water Treatment Facility Process Monitoring and Control**  
Chapter 5 focuses on source water treatment facility process monitoring, control and risk management. Robust and reliable process control and monitoring are important SWTF management tools which would enable the production of a consistent effluent quality with limited variability. The objective of this chapter is to review strategies and options to monitor and control SWTF to manage, minimize and mitigate the risks associated with SWTF process upsets and/or deviations which would have a detrimental impact on the supply water quality or production consistency. Similar benefits may accrue to the WWTPs which are not SWTFs.

The supply water quality is measured and monitored using a combination of online and bench analyses. Therefore, effective management of these tools is essential to a successful DPR program. There are a wide array of instruments and related monitoring or control applications regularly used in SWTFs – ranging from real-time source water pH monitoring to online ammonia-N and DO measurement in the biological process to control air delivery. A brief overview of the process measurement and monitoring instrumentation applicable across different treatment stages of an IRRF is provided in Table 5.1. It is important to note that all these analyzers have been in use at SWTFs and AWPFs for an extended period and site-specific evaluation may not be warranted. The driver for increased monitoring at the SWTF is to maintain a consistent delivery and quality of supply-water increases the importance of instrumentation and process monitoring within the SWTF. Figure ES-4 illustrates an example plant wide process monitoring at a SWTF producing DPR supply water.
Figure ES-4  Example of Plant-Wide Process Monitoring at a SWTF Producing DPR Supply Water
Source Water Treatment Facility Risk Management
A comprehensive hazard and risk assessment is a critical aspect of developing a robust and reliable DPR program. It is important to note that risk and hazard assessment are not new within the arena of IRRF design and operation (through a HAZOP analysis, for example). However, the pathogen-related health risks associated with DPR motivate more emphasis on assessment of potential process failures, limitations, constraints and instabilities to minimize the risks associated with DPR. Chapter 6 enumerates a variety of strategies to manage potential hazards and risks associated with the design, operation and maintenance of DPR facilities.

There are two key components to the overall risk analysis:
1) Identification and assessment of hazards and risks
2) Development of a mitigation and management plan for process control and actions when undesirable events occur (discussed in the next subsection).

There are several different hazard and risk evaluation techniques applicable to SWTF and IRRF risk assessments. This information is presented in Tables 6.1 and 6.2 of the Guideline. A utility should determine the most effective approach based on resource availability and risk analysis objective/scope as suggested in the Guideline.

Future Directions and Research Needs
This research project has taken many paths over the course of its development. Thus, there are many avenues of additional investigation and research that might be explored to further refine strategies for source control and the management of SWTFs and IRRFs. Over twenty suggestions have been made for such additional investigation or research.

Keywords:
Advanced Treatment
Advanced Treatment Water
Automation & Sensors
Biological Treatment
Chemical Indicators & Surrogates
Chemical Treatment
Collections Operations & Maintenance
Compendium
Compounds of Emerging Concern (CECs)
Direct Potable Reuse
Drinking Water Plant
Indirect Potable Reuse
Membrane Filtration
Modeling Wastewater Treatment
Monitoring
Nitrogen
Pharmaceuticals & Personal Care Products
Phosphorus
Plant Optimization
Potable Reuse
Regulatory
Resource Recovery
Source Control
Source Water
Treatment Operations & Maintenance
Wastewater
Wastewater Treatment
Wastewater Treatment Modeling
CHAPTER 1

Introduction

1.1 General Objectives of the Guideline

The primary objectives of the research project proposed by the WRRF Project 13-12:
1) Evaluate upstream wastewater treatment impacts (e.g. biological treatment through N/dN-nitrification/denitrification and other means, chemical treatment, industrial source control) on DPR source water quality and DPR processes.
2) Evaluate impact of hydraulic control mechanisms (e.g. flow equalization and source water storage buffers) on influent water quality and flow variations that “stress” the DPR process.

Variable influent water quality and the extent of source control strategy implemented in a community have a direct impact on the performance of an IPR/DPR treatment process train. In addition, utilities that own and operate wastewater treatment plants (WWTP) and advanced water purification facilities (AWP) are often separate entities with different treatment objectives (e.g. a WWTP treats to comply with discharge requirements to a water body while the AWPF treats to meet drinking water standards). A successful, reliable DPR treatment system requires the two entities working together, not only to meet their individual treatment objectives, but also to complement each other to provide a safe potable reuse supply. In a utility which houses both water and wastewater treatment facilities, it may be necessary to overcome the inherent cultural differences between the two departments to achieve a reliable DPR supply.

1.2 Project Outcomes

There are three integrated outcomes of this project which are described below.

1. Literature Compendium

   The Literature Compendium (Compendium) is a broad literature review on subjects related to links between source control in the collection system, wastewater processes operation and performance, and operations and performance of potable reuse treatment systems.

   The Compendium is published as a standalone document and available electronically via the WE&RF website at XXXXX.

2. Utility Case Studies

   A comprehensive summary of the design, operation and performance of the wastewater treatment facilities and advanced water purification facilities at each of the four participating utilities listed in Table 1.1 are included in the Case Studies. In addition to a review of the design, operation and performance of the wastewater and AWPF, these case studies provide important insights into the collection system management and source control programs implemented at each of the four utilities. Readers will find this information extremely beneficial, perhaps even using it as a set of templates from which to selectively pick and choose those strategies and approaches most beneficial and applicable to specific systems under consideration.
Table 1.1  Case Study Participants

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| Case Study 4: Singapore PUB | Source Water for IPR: Step-feed activated sludge secondary effluent and MBR filtrate blend.  
The conventional activated sludge process at Changi Water Reclamation Plant (CWRP) was partially retrofitted with MBR. The Changi NEWater Plant (CNP) receives the blended filtrate/secondary effluent to produce IPR quality water (branded NEWater).  
1. Extensive and established source control program of feed to CWRP  
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The Case Studies are also published independently on the WE&RF website but are a critical part of this Guideline document in that the lessons learned from each of the utilities has provided significant input to the findings in this Guideline. The Case Studies can be found at XXXXX.
3. Guidelines for Source Control and Source Water Treatment Facility Design and Operation

The Guideline (i.e., this document) is a culmination of the efforts of this project motivated by our findings in developing the Compendium and the Case Studies.

Many terms are either introduced in this Guideline or used interchangeably with previously defined terms common in the field. They are noted in the List of Acronyms.

This Guideline likely will be valuable to a wide range of utilities, whether they have no formal IPR program and only are thinking about IPR/DPR, a utility that is currently part of an IPR program at the study, planning or implementation level or are in the final stages of planning for DPR. The case studies and the conclusions drawn from them as well as other material gleaned from the literature and other sources should allow an increasing number of communities to plan for and implement a safe IPR/DPR program.

1.3 Key Elements of a Direct Potable Reuse Program

In the past, wastewater collection systems were often considered dumping grounds for everything from industrial wastewaters to unused pharmaceuticals from individual residences. With the advent of pre-treatment ordinances and an increasing awareness of the impact of unwanted pharmaceuticals at the WWTP, source control has become a critical factor in protecting the WWTP from unwanted contaminated influent which may carry over to the AWP.

Further, WWTP and WTP always have been different and utilize different source waters. They are almost always at different locations in a community, have different staffs with different types of skill sets and operating licenses. But all that is in a state of flux as integrated “single facilities” are being planned, designed and operated to broadly maximize the utilization of the water within a collection system to promote potable reuse. Figure 1.1 illustrates this concept.

In Figure 1.1, Source Water from home, businesses, industry and other dischargers is transported in the collection system to an Integrated Resource Recovery Facility (IRRF). The IRRF is comprised of a Source Water Treatment Facility (SWTF) and an Advanced Water Purification Facility (AWP). The SWTF provides the DPR Supply Water to the AWP. The Purified Water from the SWPF can then be used in one or more of three different DPR scenarios:

- Scenario No. 1: To replenish a storage tank (with a short detention time) for a Drinking Water Treatment Plant (WTP);
- Scenario No. 2: As the feed water for the WTP; and
- Scenario No. 3: Blended directly with drinking water in the water distribution system. WTP.

The new terminology related to the components of this integrated water management paradigm described above is warranted.

Source Water

Water contained in the collection system which will eventually serve as the source for the potable reuse processes. This may have been, or continue to be, called wastewater, sewage, or influent. We elected to use the term Source Water to convey that it should be effectively managed as an important resource. This should enable utilities to elevate the importance of source control and/or pollution prevention programs.
**Integrated Resource Recovery Facility (IRRF)**
A resource recovery facility which, in addition to functioning as a WRRF (as defined by WEF) – integrates potable reuse through an advanced water purification facility (AWPF). We elected to use the acronym IRRF to differentiate these utilities from WRRFs specifically because of the AWPF element. Thus, there must be an emphasis on integrated staff training (on both water and wastewater treatment process) and integrated system management to ensure a reliable and consistent production of supply water (see below) to the AWPF.

**Source Water Treatment Facility (SWTF)**
SWTF is a relatively new term which is the collection of unit operations which together treat the source water and produce a supply water (see below) for the AWPF. Historically, this may be referred to as a wastewater treatment plant/facility or water resource recovery facility. We elected to use the acronym SWTF to emphasize the fact that these processes must now be managed to treat a source water and consistently produce a supply water. These terms are used interchangeably in this document.

**Supply Water**
Water produced by a SWTF which may be further treated in an AWPF. Note that both the WRRF and AWPF can be within the same fence line and managed by a single entity or be separate entities. We elected to use the term Supply Water to emphasize that WRRFs are responsible for more than an effluent – indeed they are supplying water to the AWPF to meet a community’s thirst for reliable and sustainable potable water.
Figure 1.1 Illustration of Water Reuse Recovery Facility Incorporating DPR+
1.4 Structure of this Guideline

The remainder of this Guideline consists of five core chapters (Chapters 2-6) and a concluding chapter, which provide insight into the key elements of the components of a DPR program as illustrated in Figure 1.1 upstream of the AWPF.

Chapter 2 reviews the impact that the quality and flow variation of the DPR supply water can have on the design and operation of the AWP processes as well as mitigation and design considerations to maximize efficiency and performance.

Chapter 3 evaluates source control through a variety of lenses. Source control is a critical element of any potable reuse program, regardless of whether it is indirect potable reuse (IPR) or direct potable reuse (DPR). Source control is a combination of managerial and operations barriers that are implemented as part of a multi-barrier approach to potable reuse. An effective source control program can eliminate or control the discharge of pollutants into the source water which may be difficult to treat, impact maintenance and operations, impact public or environmental health, or have a deleterious impact on the supply water. This section addresses the differences between “pretreatment” programs and “source control” programs, the key elements of a source control program for DPR, understanding the effectiveness of source control, and how a source control program may or may not differ from a program implemented for an indirect potable reuse (IPR) project.

Chapter 4 provides guidance related to the configuration, process design and operation of an SWTF compatible with an AWP. The chapter focuses on four key elements: nitrogen management, flow and load variation management, sidestream management and management of Compounds of Emerging Concern (CECs). This chapter is not a primer on wastewater treatment or a review of generally accepted operational requirements for efficient SWTF operation. There are many good sources that cover these topics as noted in the Chapter 4.

Chapter 5 focuses on SWTF process monitoring, control and risk management. While Chapters 3 and 4 examine the impact of source water control and source water treatment strategies on the variability in quality and production of supply water, the objective of this chapter is to review strategies and options to monitor and control an SWTF to manage, minimize and mitigate the risks associated with SWTF process upsets and/or deviations which would have a detrimental impact on the supply water quality or production consistency.

Chapter 6 enumerates a variety of strategies to manage potential hazards associated with the design, operation and maintenance of SWTFs.

Chapter 7 summarizes the important points developed in each of the various chapters. Based on the findings from this project, comments and recommendations for future work are identified.

There are a number of facets to planning and implementing a DPR program. Each of the subject oriented chapters (i.e., Chapters 2-6) will guide and provide information related to that specific component as described above. To enable the reader to conveniently navigate the document and determine which chapters may be most relevant as a reference tool at a given time in the process of developing or implementing a potable reuse program – we have developed the DPR Planning and DPR Preparation Roadmaps shown in Figures 1.2A and 1.2B.
Figure 1.2A  Roadmap for DPR Planning: A Guide to the Key Steps Required when Planning a DPR Program
Figure 1.2B Roadmap for DPR Preparation: A Guide to Locate Information in this Document to Develop a Successful DPR Program
CHAPTE 2

How Source Control and SWTF Design and Operation Impact an AWPF

2.1 Introduction

The focus of this Chapter is to examine how source control and the design and operation of SWTF’s can impact downstream AWPF’s. In doing so, two example AWPF treatment trains which have been identified to be applicable for DPR (Walker et al., 2016), one RO based and one non-RO based, are illustrated and discussed. It should be noted, the addition of upstream flow equalization (not included in the example DPR treatment trains) is an important consideration to mitigate flow and water quality variations that may occur in the DPR supply water, as discussed further in the sections below. Further details and considerations related to treatment trains for potable reuse can be found elsewhere (Trussell et al., 2013; APAI, 2015).

For example, the process function, key design factors, and DPR supply water constituents that can impact the design and operation of individual AWP unit processes is provided and summarized. Next, information is provided and summarized with respect to the impact that poor water quality and flow variations associated with the DPR supply water can have on the design and operation of the individual AWPF unit processes. Examples of potential strategies to mitigate these impacts are also provided. Subsequent chapters of this report provide guidance on Source Control Strategies for DPR (Chapter 3) and the Design, Operation and Optimization of SWTF’s (Chapter 4), both of which can lead to increased reliability, improved operations and overall reduced cost of the downstream AWPF’s.

2.2 Example DPR Treatment Train No.1

The RO based example DPR treatment train, consisting of microfiltration (MF) or ultrafiltration (UF), reverse osmosis (RO), ultraviolet light (UV) disinfection/advanced oxidation (AOP) using hydrogen peroxide, stabilization, chlorine contact and an engineered storage buffer is illustrated in Figure 2.1. (Equalization storage could be supplied ahead of the MF/UF to simplify membrane operation.)
Figure 2.1 Example DPR Treatment Train 1 (RO based): MF>RO>UV/AOP>Chlorine Contact and Engineered Storage (Walker et al., 2016)
AWP Process Function, Key Design Factors and Key DPR Supply Water Constituents that Impact Design/Operation

The function and key design factors associated with each major unit process of example DPR Train No.1 is provided in Table 2-1. The table also provides key water quality constituents in the DPR supply water that can impact the design/operation of each unit process. As noted, in some instances, though certain water quality constituents present in the DPR supply water can impact the design of individual unit process, the impact is negated due to the location of the individual processes in the overall treatment train. For example, while the presence of inorganics such as manganese, iron, calcium, etc. can lead to increased lamp sleeve fouling in UV systems requiring cleaning mechanisms and maintenance, these constituents are removed by upstream RO process and therefore have little to no impact on the design and operation of the UV system based on its location in the overall DPR treatment train. On the contrary, constituents such as certain CECs e.g. (1,4 Dioxane, NDMA) present in the DPR supply water, which may not be completely removed by RO and have certain regulatory requirements, such as product water concentration limits and log removal requirements, may have a significant impact on the design and operation of the UV AOP process.
Table 2.1 AWP Process Function and Key Design Factors (Example DPR Treatment Train No. 1)

<table>
<thead>
<tr>
<th>AWP Process</th>
<th>Process Function</th>
<th>Key Design Factors</th>
<th>DPR Supply Water Quality Constituents that may Impact Design/Operation</th>
</tr>
</thead>
</table>
| MF/UF       | • RO pretreatment, particulate/pathogen removal. | • Net Flux  
• Recovery  
• Number of trains  
• Membrane configuration (submerged or pressurized)  
• Cleaning frequency  
• Membrane material | • Inorganic s (e.g. metal oxides, carbonates, polymers)  
• Particulate/colloidal (e.g. (suspended solids, colloids, biologically inert particles)  
• Biological/microbial (bacteria, viruses, nitrogen, phosphorus)  
• Organics – e.g. natural organic matter (primarily humic substances – measured by TOC as well as UVT, which also reflects other organic matter such as lignin and tannin). Soluble, long chain, high molecular weight organics have been shown to result in increased membrane fouling.  
• General – pH, Temp, DO |
| RO          | • Pathogen removal, organics removal, CEC removal, demineralization, nitrogen removal | • Flux  
• Recovery  
• Vessel configuration  
• Number of trains  
• Chemical Pretreatment (i.e. anti-scalant, acid addition for pH suppression)  
• Energy recovery | • Polymer/coagulant residual from SWT, but water soluble polymers are less problematic.  
• Inorganics (calcium, magnesium, chloride, silica, phosphate, barium, strontium, sulfate, chloride, fluoride, aluminum, iron alkalinity, total hardness, boron, polymers)  
• Nutrients (ammonia, nitrate, nitrite, phosphate, total phosphorus)  
• Organics – e.g. natural organic matter (primarily humic substances – measured by TOC as well as UVT, which also measures other organic matter such as lignin and tannin). Soluble, long chain, high molecular weight organics have been shown to result in increased membrane fouling.  
• Serves as a barrier for CEC’s  
• General – pH, Temp, DO, TDS. |
| UV/AOP      | • Pathogen inactivation/destruction, CEC removal | • Lamp Type  
• UV Dose and peroxide dose | • Trace organics/CECs (e.g. 1.4 Dioxane, NDMA)  
• DBP precursors  
• Efficiency/Performance – pH, Temp, UVT, Alkalinity, TOC, Nitrate, Turbidity/Suspended Solids (minor) |
<table>
<thead>
<tr>
<th>AWP Process</th>
<th>Process Function</th>
<th>Key Design Factors</th>
<th>DPR Supply Water Quality Constituents that may Impact Design/Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Target contaminant log removal</td>
<td>impact due to the location of the UV/AOP in the overall DPR train.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Peroxide residual quenching</td>
<td>• Reactor fouling/Cleaning system maintenance – Hardness, Alkalinity, Manganese, Iron, Aluminum, Magnesium, Calcium, pH, Temperature (minor impact due to location of the UV/AOP in the overall DPR train)</td>
</tr>
<tr>
<td>Stabilization/Post Treatment</td>
<td>• Remineralization / pH adjustment for corrosion control</td>
<td>• Target alkalinity, pH, hardness, phosphate</td>
<td>• Alkalinity, hardness, pH, temperature, phosphate (in general the DPR supply water quality would have little impact on Stabilization post treatment due to location in the overall DPR train).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• LSI/CCPP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chemical selection / dose rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• DPR blending scenario</td>
<td></td>
</tr>
<tr>
<td>Chlorine Contact</td>
<td>• Pathogen inactivation/destruction</td>
<td>• Target pathogen log removal</td>
<td>• Temperature, alkalinity, nitrogen content. (in general, the DPR supply water quality would have little impact on the chlorine contact process design/operation due to the location in the overall DPR train).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contact time</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chlorine Dose</td>
<td></td>
</tr>
<tr>
<td>Engineered Storage</td>
<td>• Response time to treatment failure</td>
<td>• Hydraulic Retention Time, Number of Storage tanks.</td>
<td>• Not Applicable if covered and hidden from sunlight. If exposed, growth might occur that could have traditional taste and odor issues.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• DPR supply flow variability</td>
</tr>
</tbody>
</table>
AWP Process Design and Operations Impact of Poor DPR Supply Water Quality and Flow Variations
Table 2-2 summarizes the potential impact poor water quality and flow variations associated with the DPR supply water can have on the operation and design of the various process components of example DPR Treatment Train No.1. In addition, example strategies aimed to mitigate such impacts on the AWP process performance are provided.
Table 2.2  Impact and Mitigation Strategies of Poor DPR Supply Water Quality and Flow Variations on AWP Processes (Example DPR Treatment Train 1)

|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| MF/UF       | • **Operations Impact**: Increased membrane fouling (requiring reduced flux operation) or decreased time between cleaning operations. Diurnal flow variations in DPR supply water may require MF/UF trains to be taken offline during low flow periods limiting the overall AWPF production capacity and increase operator work-load. Other considerations include clogging of pre-strainers resulting in high operating pressure/frequent cleaning and possible interruption in feed flow supply available to MF/UF.  
   • **Design Impact**: Lower design flux and space for additional membrane racks may be required resulting in higher membrane equipment costs. | • Optimize SWTF Design/Performance (See Chapter 4)  
   • Provide additional pre-treatment (e.g. chloramines, inline coagulation, ozone/BAC)  
   • Provide SWTF flow equalization (e.g. upstream flow equalization of the DPR supply water to dampen diurnal flow and increase ease of increasing AWPF production capacity. Consider flow equalization within the SWTF to improve biological process effluent quality and reduce membrane fouling. - See Section 4.3 for more information).  
   • Implement comprehensive source control strategies (See Chapter 3) |
| RO          | • **Operational Impact**: increased scaling/fouling resulting in decreased time between cleaning operations and/or reduction in recovery. Diurnal flow variations may require RO trains to be taken offline (or operated at lower flux/higher recovery) during low flow periods and operated at higher flux during high flow periods. RO permeate may not meet water quality requirements (e.g. nitrogen and boron. Without flow equalization, RO skids may need to be taken offline during low flow periods increasing operator work-load.  
   • **Design impact**: Additional RO trains may be required to accommodate flow variation, Additional treatment (e.g. second pass RO) may be required to meet effluent water quality requirements. | • Implement comprehensive source control strategies (See Chapter 3)  
   • Optimize SWTF Design/Performance (See Chapter 4)  
   • Optimize chemical pre-treatment and monitoring  
   • Provide SWTF flow equalization |
| UV/AOP      | • **Operational Impact**: increased UV energy and/or peroxide dosing required to meet target product effluent water quality requirements. Diurnal flow variations may require UV reactor power to be reduced or reactors be taken offline during low flow periods. Increased peroxide. | • Implement comprehensive source control strategies (See Chapter 3)  
   • Optimize SWTF Design/Performance (See Chapter 4) |
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>residual in UV/AOP effluent will increase chlorine dose required for downstream process to achieve target CT.</td>
<td>• Conduct bench scale testing to full characterize influent quality and optimize control strategy with regards to UV energy and peroxide dose per selected equipment supplier.</td>
</tr>
<tr>
<td>Chlorine Contact</td>
<td>• <strong>Design Impact:</strong> increased number of UV reactors and peroxide dosing system with wide range of turndown capabilities. Need for larger capacity peroxide quenching system such as chlorine dosing</td>
<td>• Provide SWTF flow equalization</td>
</tr>
<tr>
<td></td>
<td><strong>Operational Impact:</strong> minimal impact if located downstream of RO and UV/AOP. If chlorine contact is located upstream of MF/UF, there would be an increase CT required for a given target pathogen removal as well as increased DBP formation potential. Increased oxidant demand, variable water quality, difficulty achieving break-point, etc. Flow variations would require turndown of chemical dosing pumps.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <strong>Design Impact:</strong> Minimal impacts from DPR supply water quality if located downstream of RO and UV/AOP however, larger chlorine contact basin/higher chlorine dose may be required to achieve target pathogen removal if located upstream of MF/UF. Chemical dosing system design to accommodate range of flow variation.</td>
<td></td>
</tr>
</tbody>
</table>
| Stabilization/ Post Treatment | **Operational Impact:** water quality impacts minimal if located downstream of RO and UV/AOP however, increased organics/TOC may impact the bios-stability of the AOP effluent. Need to quench of peroxide in AOP effluent. Flow variation may result in over or under dosing of chemical dosing systems (particularly lime systems) leading to increased turbidity in AWP product water | • Optimize SWTF Design/Performance (See Chapter 4)  
• Provide SWTF flow equalization |
<table>
<thead>
<tr>
<th></th>
<th>• <strong>Design Impact:</strong> larger hydrogen peroxide quenching system; chemical systems design to consider wide range of turndown</th>
<th></th>
</tr>
</thead>
</table>
| Engineered Storage  | • **Operational Impact** may require use of multiple storage tanks during high flow period to equalize flow to DPR blending scenario  
• **Design Impact** Diurnal flow variation may require engineering storage to be sized for flow equalization of AWP product water during low flow period. | • Provide SWTF flow equalization |
2.3 Example DPR Treatment Train No.2

The non-RO based example DPR treatment train, consisting of pre-ozonation (optional), chemically enhanced flocculation/sedimentation, ozone/biological activated carbon (BAC) filters, granular activated carbon (GAC), UV disinfection, chlorine contact and an engineered storage buffer is illustrated in Figure 2.2. Note because this treatment train does not remove total dissolved solids (TDS) a closed loop recycle system will occur if the DPR product water is recycled back to the sewer-shed as potable water and may increase the TDS of the DPR product water above an acceptable level. One mitigation strategy would be to incorporate a side stream RO process, which would require brine disposal and increased costs.

![Diagram of Example DPR treatment train 2 (non RO based): Ozone>Flocculation/Sedimentation>Ozone>BAC>GAC>UV Disinfection> Chlorine Contact and Engineered Storage (Walker et al., 2016)](image)

AWP Process Function, Key Design Factors and Key DPR Supply Water Constituents that Impact Design/Operation

The function and key design factors associated with each major unit process associated with example DPR Train No. 2 is provided in Table 2-3. The table also provides key water quality constituents in the DPR supply water that can impact the design/operation of each unit process. As noted, in some instances, though certain water quality constituents present in the DPR supply water can impact the design of individual unit process, the impact is negated due to the location of the individual processes in the overall treatment train. An example would be GAC which is impacted by constituents such as TOC, iron, manganese, turbidity which would be reduced by the upstream processes.
<table>
<thead>
<tr>
<th>AWP Process</th>
<th>Process Function</th>
<th>Key Design Factors</th>
<th>DPR Supply Water Quality Constituents that Impact Design/Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone (optional pre-ozonation step)</td>
<td>• Pathogen inactivation/destruction, chemical removal, organics oxidation</td>
<td>Ozone dose contact time Application/injector type</td>
<td>• Turbidity, organic/ inorganics (iron, manganese, sulfides, nitrite, bromide, etc.) that contribute to oxidant demand</td>
</tr>
<tr>
<td></td>
<td>• Coagulation benefits</td>
<td></td>
<td>• Scum forming material</td>
</tr>
<tr>
<td>Chemically enhanced Flocculation/Sedimentation</td>
<td>• In combination with BAC filters, provides particulate/pathogen removal</td>
<td>Coagulant type/dose Mixing speed</td>
<td>• pH, turbidity, organic matter, alkalinity, hardness, temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydraulic retention time Settling / overflow rate</td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>• In combination with BAC filters, provides pathogen inactivation and chemical / organics removal</td>
<td>Ozone dose Contact time Application/injector type</td>
<td>• Turbidity, organic/ inorganics (iron, manganese, sulfides, nitrite, bromide, etc.) that contribute to oxidant demand</td>
</tr>
<tr>
<td>BAC Filters</td>
<td>• In combination with Ozone, provides chemical / organics removal, and combined with C/F/S provides pathogen removal (if operated like biological filter)</td>
<td>Type/size/depth of filter media EBCT Backwash frequency/duration Number of Filters Filter loading rate</td>
<td>• TOC, temperature, turbidity, iron, manganese</td>
</tr>
<tr>
<td>GAC Filters</td>
<td>• Provides removal of chemical and organics removal not removal bu upstream processes</td>
<td>GAC type EBCT Backwashing frequency/duration</td>
<td>• TOC, temperature, turbidity, iron, manganese</td>
</tr>
<tr>
<td>UV Disinfection</td>
<td>• Pathogen inactivation/destruction</td>
<td>• UV dose • Lamp type • Flow • UVT • Number of reactors • Lamp type</td>
<td>• Efficiency/Performance –UVT, Turbidity / Suspended Solids, temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Reactor fouling/Cleaning system maintenance – Hardness, Alkalinity, Manganese, Iron, Aluminum, Magnesium, Calcium, pH, Temperature (minor impact due to location of the UV)</td>
</tr>
<tr>
<td>AWP Process</td>
<td>Process Function</td>
<td>Key Design Factors</td>
<td>DPR Supply Water Quality Constituents that Impact Design/Operation</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------</td>
<td>----------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Chlorine Contact    | • Pathogen inactivation     | • Target pathogen log removal  
|                     |                             | • Contact time             | Temperature, alkalinity, TOC, ammonia, nitrite                   |
|                     |                             | • Chlorine Dose            |                                                                 |
| Engineered Storage  | • Response time to treatment failure | • Volume, Hydraulic Retention Time, Number of Storage tanks | Not applicable                                                 |
AWP Process Design and Operations Impact of Poor DPR Supply Water Quality and Flow Variations

Table 2.4 summarizes the potential impact poor water quality and flow variations associated with the DPR supply water can have on the operation and design of the various process components of example DPR Treatment Train No.2. In addition, example strategies aimed to mitigate such impacts on the AWP process performance are provided. Of the various unit processes present in the non-RO based treatment train example, perhaps the process most significantly impacted by poor DPR supply water quality would be the ozone processes. Poorly oxidized and non-nitrified secondary effluent have been shown to contain high concentrations of NDMA precursors, and form NDMA when ozonated (Serna et al., 2014). In addition, high concentrations of bromide in DPR supply water would result in the formation of bromate to concentrations the MCL. Potential mitigation strategies could include optimizing SWTF to oxidize pre-cursors, targeting pre-cursors via source control or modifying the design of the DPR treatment train to include downstream processes such as RO and AOP which would be designed to reduce DBP concentrations to meet regulatory requirements.
|-------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Pre-Ozonation                       |  **Operations Impact:** increased ozone demand. During low flow periods, may be difficult to achieve target ozone dose and ozone residual may not be detected at the end of contact basin. May result in DBP formation such as NDMA and bromide which could impact the selection of the downstream AWP processes.  

  **Design Impact:** ozone capacity, ozone injector design and ozone residual monitoring to accommodate wide range of ozone demand. |
|                                    |  • Implement comprehensive source control strategies (See Chapter 3)  
  • Optimize SWTF Design/Performance (See Chapter 4)  
  • Provide SWTF flow equalization  
  • Select downstream treatment processes which are effective at DBP removal |
| Chemically Enhanced Flocculation/Sedimentation/BAC |  **Operational Impact:** Increased chemical usage (lime, coagulant); shorter BAC filter runs and increased backwashing due to increase organic loading, increased effluent turbidity, negative impact on filter biology and performance.  

  **Design impact:** increased number of filters to maintain capacity |
|                                    |  • Implement comprehensive source control strategies (See Chapter 3)  
  • Optimize SWTF Design/Performance (See Chapter 4) |
| Ozone/BAC                           |  **Operational Impact:** See pre-ozonation; See Chemically Enhanced Flocculation/Sedimentation/BAC.  

  **Design Impact:** increased number of filters to maintain capacity |
|                                    |  • Implement comprehensive source control strategies (See Chapter 3)  
  • Optimize SWTF Design/Performance (See Chapter 4) |
| GAC                                 |  **Operational Impact:** Shorter filter runs, increase backwashing, increase frequency of GAC replacement  

  **Design Impact:** increased number of GAC filters, larger backwash storage basin, may need to design for DBP removal resulting from pre-ozonation |
|                                    |  • Implement comprehensive source control strategies (See Chapter 3)  
  • Optimize SWTF Design/Performance (See Chapter 4) |
| UV Disinfection                     |  **Operational Impacts:** DPR supply water quality variability could impact the upstream process (Ozone/BAC) performance thereby affecting the UVT and power/performance of the UV system. Flow variations may require turn down or power adjustment of UV reactors.  

  **Design Impact:** UV reactor design to accommodate wide range of flow and UVT variations |
|                                    |  • Optimize SWTF Design/Performance (See Chapter 4)  
  • Provide SWTF flow equalization |
<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine Contact</td>
<td>• <strong>Operational</strong> Flow variations would require adjustment of chemical dosing systems.</td>
<td>• Optimize SWTF Design/Performance (See Chapter 4)</td>
</tr>
<tr>
<td></td>
<td>• <strong>Design Impact:</strong> larger chemical dosing system design to consider wide range of turndown required</td>
<td>• Provide SWTF flow equalization</td>
</tr>
<tr>
<td>Engineered Storage</td>
<td>• <strong>Operational Impact</strong> may require use of multiple storage tanks during high flow period to equalize input to downstream use</td>
<td>• Provide SWTF flow equalization</td>
</tr>
<tr>
<td></td>
<td>• <strong>Design Impact</strong> Diurnal flow variation may require engineering storage to be sized for flow equalization of AWP product water during low flow period.</td>
<td></td>
</tr>
</tbody>
</table>
2.4 References


Walker, T., et al., Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of a DPR Scheme, Copyright (in progress) by the WateReuse Research Foundation Project Number WRRF-13-03, WRRF Product Number 13-03-1.


Serna, M., Trussell, R., Gerringer, F., (2014) Ozone Pretreatment of a Non Nitrified Secondary Effluent Before Microfiltration, Copyright by the WateReuse Research Foundation Project Number WRR-10-11, WRRF Product Number 10-11-1.

WRRF 13-12 Support Documentation (Literature Review and Case Studies)
CHAPTER 3

Source Control Strategy Guidelines for Direct Potable Reuse

3.1 Introduction

Source control is a critical element of any direct potable reuse (DPR) program just as it is for any indirect potable reuse (IPR) program. It is a combination of managerial and operations barriers that are implemented as part of a multi-barrier approach to eliminate or control the discharge of compounds of emerging concern (CECs) to wastewater that may be difficult to treat, impact maintenance and operations, and/or may impair the final quality of the treated water intended for DPR (APAI, 2015; Tchobanoglous et al., 2015).

This Chapter addresses:
- Understanding the differences between “pretreatment” programs and “source control” programs,
- Understanding the key elements of a source control program for DPR,
- Understanding the effectiveness of source control, and
- Understanding how a source control program may or may not differ from a program implemented for an indirect potable reuse (IPR) project.

The information presented in this chapter is primarily based on the U.S. perspective of pretreatment/source control and may differ from programs outside of the U.S. Some noteworthy examples of systems in place in other countries are also described.

3.2 Pretreatment versus Source Control

Although often used interchangeably in the world of potable reuse, the terms “pretreatment” and “source control” (sometimes referred to as “enhanced” source control) are not necessarily the same thing. For this Guideline document, source control and enhanced source control have the same meaning. The following subsections, beginning with pretreatment, attempt to provide the distinctions between pretreatment and source control.

3.3 Pretreatment Programs

Pretreatment programs are mandated under sections 212 and 502(4) of the Clean Water Act (CWA) for most, but not all, Publicly Owned Treatment Works (POTWs) that discharge to waters of the U.S. (e.g., surface waters). Thus, “approved” pretreatment programs are a component of the National Pollutant Discharge Elimination System (NPDES) program and provisions to implement pretreatment programs are included in NPDES permits issued by states to POTWs. The U.S. Environmental Protection Agency (U.S. EPA) or authorized NPDES state approves a POTW’s pretreatment program to ensure it meets federal requirements. The U.S EPA promulgated General Pretreatment Regulations (40 Code of Federal Regulations (CFR) 403) to define terms and set responsibilities for federal, state, local government, and industries to achieve the National Pretreatment Program objectives. The regulations only apply to industries and other non-domestic wastewater sources. The term “pretreatment” is defined in regulations as the reduction of the amount of pollutants, the elimination of pollutants, or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or introducing such pollutants into a POTW.
The objectives of the National Pretreatment Program (40 CFR 403.2) are to:

- Prevent the introduction of pollutants into a POTW that will interfere with the operation of the POTW, including interference with its use or disposal of biosolids. “Interference” is defined as a discharge which alone or in combination with a discharge or discharges from other sources (1) inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, uses or disposal, and (2) is therefore a cause of a violation of any requirement in a POTW’s NPDES permit.

- Prevent the introduction of pollutants into a POTW that will pass through the treatment works or otherwise be incompatible with the treatment works. “Pass through” is defined as a discharge that exits the POTW into waters of the U.S. in quantities or concentrations, which, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any requirement in a POTW’s NPDES permit.

- Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

- POTWs within their legal authority typically include as an additional objective to protect the POTWs’ sewage treatment system, infrastructure, and workers.

- Pretreatment programs in countries outside of the U.S. are achieved by regulations that specify the allowable volume of discharge from each industry as well as a range of mass loading or concentration limits for parameters known to be present on the industrial site and/or present in the discharge. These concentration limits are there to protect the collection system, the health of the workers and the performance of the wastewater treatment plants (WWTPs) or POTWs.

3.3.1 Mandatory Approved Pretreatment Program Requirements

POTWs must enforce general prohibitions and specific prohibitions that apply to all non-domestic users. The general prohibitions disallow an industry from discharging a pollutant or pollutants that cause pass through or interference. The specific discharge prohibitions listed in 40 CFR Section 403.5(b) exclude the discharge of:

- Pollutants that may create a fire or explosion hazard in the sewer system or at the POTW.
- Pollutants that is corrosive, including any discharge with a pH of less than five.
- Solid or viscous pollutants, in sufficient amounts, that will cause obstruction or blockage of flow.
- Any pollutants discharged in sufficient quantity to interfere with the operation of the POTW.
- Heat in such quantities that the temperature at the POTW Treatment Plant exceeds 104 °F or is hot enough to interfere with biological treatment processes.
- Petroleum oil, non-biodegradable cutting oil, or other products of mineral oil origin in amounts sufficient to cause interference or pass-through.
- Pollutants that result in the presence of toxic gases, vapors, or fumes at the POTW in sufficient amounts that may cause acute worker health and safety problems.
- Any trucked or hauled pollutants, except at discharge points designated by the POTW.

POTWs also must enforce U.S. EPA’s categorical pretreatment standards. These are technology-based numeric limits that have been developed in accordance with section 307 of the CWA to limit the pollutant discharges to POTWs from specific process wastewaters from industrial users (IUs.) These national technology-based standards apply to an IU regardless of whether the POTW has an approved pretreatment program or the IU has been issued a control mechanism or permit. The standards are established based on the list of priority pollutants in 40 CFR Section 401.15, which contains 65 entries, some of which are for groups of pollutants.

Approved pretreatment programs must contain at a minimum, the following six elements listed in Table 3.1.
### Table 3.1 Minimum Approved Pretreatment Program Elements

<table>
<thead>
<tr>
<th>Program Element</th>
<th>Description – Must Enable a POTW to:</th>
<th>U.S. EPA Resources</th>
</tr>
</thead>
</table>
| **Legal Authority (ordinance, rules, multijurisdictional agreements as applicable)** | – Deny or condition discharges to the POTW  
– Require compliance with pretreatment standards and requirements  
– Control industrial discharges through permits, orders, or similar means  
– Require compliance schedules and submission of reports to demonstrate compliance  
– Inspect and monitor industries  
– Obtain remedies for industrial noncompliance  
– Comply with confidentiality requirements  
– Enter into multijurisdictional agreements with entities that discharge to a POTW, but are outside the POTW’s legal jurisdiction to ensure that the entity and its IUs meet the POTW’s pretreatment program requirements (fees, inspection rights, limits, monitoring, reporting, etc.) | Introduction to the National Pretreatment Program  
Model Pretreatment Ordinance  
Multijurisdictional Pretreatment Programs Guidance Manual |
| **Procedures** | – Identify and locate all industries subject to the pretreatment program  
– Identify the character and volume of pollutants contributed by industries  
– Notify industries of applicable pretreatment standards and requirements  
– Receive and analyze reports from industries  
– Sample and analyze industrial discharges, including hauled wastes  
– Evaluate the need for control plans for spills  
– Investigate instances of noncompliance  
– Comply with public participation requirements for program changes and publication of industries in significant noncompliance with pretreatment requirements  
– Develop forms and checklists to implement the pretreatment program. | Guidance Manual for Preventing Interference at POTWs  
Guidance Manual for the Control of Wastes Hauled to POTWs  
Industrial User and Sampling Manual for POTWs  
Industrial User Permitting Guidance Manual |
<p>| <strong>Funding</strong> | – Maintain sufficient resources and qualified personnel to carry out the authorities and procedures specified in its approved pretreatment program | Introduction to the National Pretreatment Program |</p>
<table>
<thead>
<tr>
<th>Program Element</th>
<th>Description – Must Enable a POTW to:</th>
<th>U.S. EPA Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Limits for Industries (apply at the end-of-pipe discharge)</td>
<td>- Develop local limits for CECSs to address the specific needs and concerns of a POTW, its sludge, and its receiving waters &lt;br&gt; - For an approved pretreatment program, local limits must be technically based and prepared considering the procedures in U.S. EPA’s <em>Local Limits Development Guidance</em> &lt;br&gt; - If authorized in an approved pretreatment programs, POTWs can develop and impose best management practices (BMPs) as local limits/pretreatment standards &lt;br&gt;&lt;em&gt;Note: some POTWs establish the legal authority to develop local limits for uniform local limits (apply throughout the service area), categories of industries, individual industries, or on a case-by-case basis&lt;/em&gt;</td>
<td>Local Limits Development Guidance&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>Enforcement Response Plan</td>
<td>Develop and implement an enforcement response plan that contains detailed procedures indicating how the POTW will investigate and respond to instances of industrial noncompliance – it should include an enforcement response guide, which is a matrix that describes the types of violations and the POTW’s range of appropriate enforcement options</td>
<td>Guidance for Developing Control Authority Enforcement Response Plans&lt;sup&gt;l&lt;/sup&gt;</td>
</tr>
<tr>
<td>Industrial Inventory</td>
<td>Prepare, update, and submit to the applicable U.S. EPA Region or authorized state a list of all IUs and identify them by appropriate classification: Significant Industrial Users (SIUs), including Categorical Industrial Users (CIUs), non-significant IUs, non-significant CIUs, and middle tier CIUs</td>
<td>Introduction to the National Pretreatment Program&lt;sup&gt;q&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Notes for Table 3.1

j. An SIU is defined as an industry subject to categorical pretreatment standards except non-significant IUs; and any other IU that (1) discharges an average of 25,000 gallons per day (gpd) or more of process wastewater to the POTW, (2) contributes a process waste stream that makes up 5 percent or more of the average dry-weather hydraulic capacity of the POTW wastewater treatment plant, (3) contributes a process waste stream that makes up 5 percent or more of the organic capacity of the POTW wastewater treatment plant, or (4) is designated as an SIU by the POTW based on the reasonable potential for adversely affecting treatment plant operation or violating any pretreatment standard.

Additional information and resources can be found on authorized state’s pretreatment program websites.

Pretreatment programs must also address toxic and hazardous wastes by: (1) monitoring wastewater treatment plant influent and effluent for toxic or hazardous pollutants listed in 40 CFR Section 122, Appendix D, Table V; (2) enforcing the pretreatment regulations (40 CFR Section 403.12(p)) that require industries to provide written notification to the POTW, U.S. EPA, and the state hazardous waste authority of the discharge of a hazardous waste into a POTW; and (3) evaluating information available in the U.S. EPA’s Toxic Release Inventory, which contains estimates regarding some hazardous chemicals manufactured, processed, or used by industries in specific sectors and discharged to POTWs (see the EPA’s Discharge Monitoring Report (DMR) Pollutant Loading Tool).

3.3.2 Who Must Have an Approved Pretreatment Program?

Not all POTWs with NPDES permits must develop and implement an approved pretreatment program. Authorized states or the U.S. EPA may require an approved pretreatment program when the POTW (or combination of POTWs operated by the same authority) meets one of these conditions:

- The total design flow of the POTW is greater than 5 million gallons per day (mgd);
- Industrial or commercial customers of the POTW discharge pollutants into the wastewater system that either pass through the treatment plant or interfere with its operation; or
- One or more industrial or commercial users of the POTW meet the definition of a categorical industrial user.
Consequently, there are POTWs with NPDES permits, POTWs that discharge to land, and POTWs that only recycle reclaimed water that are not required to implement pretreatment programs. For POTWs with types of discharge scenarios, states may have minimum requirements included in permits to develop and implement some type of program, but it does not have to be an approved program. These kinds of non-approved programs typically include prohibitions and notification requirements. Thus, for potable reuse projects (DPR and IPR) it will be important to determine if at a minimum an approved pretreatment program or some type of program is in effect.

3.4 Source Control Programs and Strategies

What is the progression from a pretreatment program of some type to a source control program for potable reuse?

As a starting point, consider the standards and minimum program elements of an approved pretreatment program as a baseline with the added provision that the focus be expanded to protection of the drinking water supply that is being created as part of the potable reuse program.

For most POTWs, the primary focus of operating wastewater treatment plants and their pretreatment programs is to meet discharge or non-potable reuse requirements. Because a program is now part of an integrated water supply project, the goals of the source control should shift to providing a higher quality wastewater that in turn can improve the operations of the project’s advanced water purification facility (AWPF), and thus the quality and reliability of the final product water which flows to a drinking water treatment plant (WTP).

What are the key considerations when developing a source control program for potable reuse and in particular, DPR?

- Are the program requirements mandatory or voluntary? At this point, most states do not have a set of comprehensive source control requirements for potable reuse projects, thereby allowing for changes to approved or non-approved pretreatment programs that support potable reuse to occur on a voluntary basis. Even states with IPR regulations, such as California’s 2014 groundwater replenishment regulations (California Code of Regulations, Title 22, Chapter 3, Water Recycling Criteria), provide a framework for programs, but allow innovation to occur on a project-by-project basis.
- Should the programs be uniform? A one-size-fits-all approach probably should not apply. Rather it should be a function of the size of the community, the number of industrial and commercial dischargers, the other potable reuse program managerial, operational, and technical barriers selected for the project, and the type of DPR project. For example, one important element for a source control program is the industrial inventory (the types of industries, locations within a sewershed, and the chemicals/pollutants that could be discharged). If you are a large municipality, you should probably develop a computerized geographical information mapping system (GIS) that can be used to rapidly identify and address discharges of pollutants. If you are a small community with a small number of industries, a GIS-based system would not be necessary, but the industrial inventory should be kept current.
- Should a program for IPR be different than a program for DPR? The answer is probably no, although there may be an argument that the closer the DPR program is to the customer (e.g., pipe-to-pipe DPR), the source control program (as well as other managerial, operations, and
treatment barriers) should be enhanced further. One tool to address this question is through a quantitative relative risk assessment (see Subsection 3.4.1). Information on source control programs for IPR projects is presented in the literature review and case studies sections of the report.

- Tchobanoglous et al. (2015) and APAI (2015) provide principles and examples of source control for DPR. Shown in Figure 3-1 is a summary of critical elements and considerations of a successful source control program. Table 3.2 builds on the above noted referenced and Figure 3-1 in significant detail and may be valuable to develop a template for source control. Note that this information is predicated on the premise that many if not all the U.S. federal pretreatment program requirements have been implemented as a baseline.

The California Code of Regulations, Title 22, Section 60320.206 (for surface application) and Section 60320.206 for subsurface application, set forth the source control requirements for groundwater replenishment projects that use recycled water. Entities that supply recycled water to a groundwater replenishment project must administer a comprehensive source control program that includes: (1) an assessment of the fate of State Water Resources Control Board Division of Drinking Water (DDW) and the applicable Regional Water Quality Control Board (RWQCB)-specified contaminants through the wastewater and recycled water treatment systems; (2) provisions for contaminant source investigations and contaminant monitoring that focus on DDW and RWQCB-specified contaminants; (3) an outreach program to industrial, commercial, and residential communities; and (4) an up-to-date inventory of contaminants.

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**Figure 3.1**   Key Elements and Considerations when developing a Source Control Program

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Guidelines for Source Water Control Options and the Impact of Selected Strategies on Direct Potable Reuse  
3-7
### Amended Source Control Program Elements

<table>
<thead>
<tr>
<th>Description</th>
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<tbody>
<tr>
<td>- Review ordinances (or regulations) to make sure there is sufficient power to develop and implement source control measures to protect recycled water quality and the ability of the wastewater treatment plant and AWP to reliably produce recycled water for DPR</td>
</tr>
<tr>
<td>- Specific focus areas for the review and any revisions include the authority to establish local limits to control CECs; to control all industries, categories of industries, and individual industries; to terminate industrial flows (on a temporary or permanent basis) if they pose a threat to the quality of recycled water; to use BMP or alternative control measures; and to include provisions that allow the POTW to take any actions as necessary to protect a DPR project</td>
</tr>
<tr>
<td>- Look at ordinances in place for existing DRP and IPR projects and ask project sponsors about the kinds of changes they would like to enact as part of future amendments to further strengthen their legal authority</td>
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<tr>
<td>- Ensure that industrial discharge permits and other control mechanisms can effectively regulate and reduce the discharge of CECs for DPR</td>
</tr>
<tr>
<td>- Review and revise permits on a regular cycle (for example every three years) to adapt to any changing conditions, as needed</td>
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<tr>
<td>- Consider alternative control mechanisms, such as BMPs or self-certification for zero discharge of pollutants for classes of industries or commercial businesses such as dry cleaners (solvents) and radiator shops (metals, solvents)</td>
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<tr>
<td>- Include provisions that industries must notify the POTW during periods of upsets, maintenance/cleaning or spills</td>
</tr>
<tr>
<td>- Consider managing hauled waste. If any SWTP/ AWT is making DPR effluent then the acceptance of hauled waste should be scrutinized closely as it can contain unknown, uncontrolled and intermittent source of constituents.</td>
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<tr>
<td>- Revise local limits to include a broader spectrum of CECs such as regulated and non-regulated constituents that are relevant for DPR, such as drinking water contaminants, advisory levels, or CECs</td>
</tr>
<tr>
<td>- Consider local limits for pollutants that lead to conditions that could impact wastewater treatment or AWP operations such as fouling, scaling, etc.</td>
</tr>
<tr>
<td>- Use BMPs for local limits for industrial and commercials discharges in cases where BMPs would be more effective than traditional local limits</td>
</tr>
<tr>
<td>- Consider evaluating the adequacy of local limits more frequently than required by an NPDES permit</td>
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<tr>
<td>- Contributory flow and mass based permitting is more specific and requires more manpower to manage the program. Staffing for permitting and enforcement will have to be increased.</td>
</tr>
<tr>
<td>- Regularly collect and update data for CECs in domestic sewage, through the wastewater treatment plant unit processes, and AWP unit processes to identify and prioritize CECs for regulation thereby facilitating the local limits derivation process</td>
</tr>
<tr>
<td>- Use a risk-based approach to prioritize CECs (see Section 2.3.1)</td>
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<tr>
<td>- Review your list of prohibitions to determine if they should be expanded to address DPR water quality</td>
</tr>
<tr>
<td>- Develop and maintain a frequently updated comprehensive inventory of industries and businesses – consider if it makes sense for a service area to make the inventory part of a GIS system</td>
</tr>
<tr>
<td>- Consider broadening the definition of a significant industrial user (SIU) to include industries that use or discharge CECs relevant to DPR</td>
</tr>
<tr>
<td>- Work with the local hazardous waste agency to identify industries that should be permitted</td>
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<tr>
<td>Program Element</td>
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</table>
| **Chemical inventory program** | Consider if you want to accept waste-hauler discharges at the wastewater treatment plant (even with monitoring and manifest programs, these kinds of loads present a habitual potential to hide illegal or hazardous loads)  
Consider if you want to bypass or segregate certain types of industrial discharges to the wastewater treatment plant that serves as feed water to the AWPF (for example centralized hazardous waste treatment systems, petroleum refineries, etc.)  
Develop and maintain a frequently updated database of the chemicals stored and inventory volumes annually used by industrial and commercial dischargers and manufacturers in the service area that are part of the industrial inventory. Potentially, this can be accomplished under SARA 313 since most industries must report the chemicals used on site so getting access to that database or merging that program with the source control might be something to consider.  
Consider developing fact sheets or links to online chemical references (like the Merck Index)  
Work with the local hazardous waste agency to identify chemicals of concern if discharged to the sewer |
| **Industrial Pretreatment and Spill Containment** | Review the adequacy of industrial treatment systems considering local limits and prohibitions  
Evaluate the adequacy of spill containment systems |
| **Monitoring** | Ensure that monitoring programs conducted by the POTW (sewershed, influent, effluent, AWPF product water) and industries address CECs for DPR  
Evaluate the adequacy of monitoring frequencies  
Consider advanced monitoring approaches for industries unwilling to cooperate or suspicious industries that involve surveillance (upstream/downstream monitoring) and other clandestine methods (such as setting up dummy automated samplers at industries)  
If you have industries that work 24 hours per day, consider organizing an inspection/monitoring shift that can conduct inspections during graveyard shifts (times when an industry may be tempted to illegally discharge)  
Consider working with your local district attorney’s office for criminal offenses  
Consider setting up a tipster hotline (and potentially rewards) for information on illegal discharges |
| **Enforcement** | Ensure that the enforcement response program can rapidly identify and respond to discharges of POCs for DPR  
Evaluate enforcement options so that you have a suite of mechanisms to adequately and promptly address all potential violations  
Evaluate the adequacy of an enforcement tracking system that enables one to determine if an industry is appropriately conforming with an enforcement action and the time for coming into compliance |
| **Industrial Assistance** | Assist and encourage industries and businesses that use or discharge CECs to evaluate pollution prevention options, including chemical substitution – but make sure that one is not exchanging one problem for another (e.g., make sure there is some type of systems assessment involved) |


1 It is possible to set up a combination of real and dummy automated samplers at industries suspected of discharging CECs at levels of concern. In some cases, the samplers are permanent installations. The industrial will not know if the dummy (which sounds like a functioning sampler) is real or not. POTWs who have used this approach have seen dramatic reductions in CECs. However, this approach involves resources for equipment and staff to collect samples, verify the samplers are working and have not been tampered with by the industry.
<table>
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<tr>
<th>Program Element</th>
<th>Description</th>
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| **Multiple Jurisdictional Coordination and Legal Authority** | - Provide compliance assistance and permit assistance to support the DPR program (this could include information on a website, workshops, webinars, resource materials, etc.)  
- Consider forming an industry advisory council made up of members of the industrial service area – the group can be used as a sounding board for implementation of new requirements, serve as a spokesperson for the POTW, etc.  
- For projects with multiple agency involvement (particularly when a separate agency treats the wastewater supplied to the agency that produces the reclaimed water used for DPR), consider entering into a memorandum of understanding (MOU) or other contractual agreement so that appropriate source control actions can be taken if necessary to protect reclaimed water quality. The MOU would establish the compliance hierarchy first comply with federal categorical limits – then comply with local prohibitions – then comply with technically based local limits which would include limits to ensure that the quality of DPR product will be maintained.  
- For POTWs that receive industrial wastewater from an agency outside its service area, ensure the agreement to accept and treat the wastewater includes provisions whereby the source control program from the external agency is commensurate with the DPR source control program and that appropriate actions can be taken by the POTW or the external agency if necessary to protect reclaimed water quality |
| **Industrial Outreach**         | - Provide outreach to industries on DPR  
- Consider developing industrial stewardship programs so that industries are aware that they are part of an integrated water management system  
- Develop award programs for industries that consistently comply with discharge requirements that include public recognition in the newspaper, city council meetings, op-ed articles in the newspaper, etc. |
| **Public Outreach**             | - Provide outreach to the public regarding proper disposal of pharmaceuticals and household products that contain CECs  
- Consider developing household hazardous waste collection programs for disposal of CECs  
- Consider working with pharmacies to develop drug take back programs or working with a regional agency to develop an ordinance for take back programs\(^2\)  
- Consider developing school education programs for the wastewater management program that addresses potable reuse  
- Consider creating an education center or demonstration facility as part of the AWPF that provides information on DPR  
- Develop a cooperative program with cities, counties or other jurisdictions within the POTW and AWPF service area to disseminate information to the public and policy makers |
| **Project Interagency Coordination** | - Ensure that there is communication plan for the POTW operations and source control staff, the AWPF operations staff, and the WTP operations staff that is followed when events or actions occur that impact the quality of raw sewage, treated wastewater, and AWP water – this plan will be tied to critical control point monitoring and will help distinguish when source control actions should be taken to rapidly respond to correct a problem, will include key responsibilities and decision points to either investigate or mitigate CECs, and if necessary to divert flow away from the wastewater treatment plant and/or the AWPF until the situation is stabilized |

<table>
<thead>
<tr>
<th>Program Element</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>– Engage with other DPR and IPR source control program to build on lessons learned, effective approaches, and new methods – working together provides support and opportunities for program enhancements</td>
</tr>
<tr>
<td></td>
<td>– Before taking source control actions, check with collection systems staff, wastewater treatment operations staff, and AWPF operations staff about conditions at the time an event occurred (such as maintenance, cleaning, chemical addition for sewers, diversion of flows, etc.)</td>
</tr>
</tbody>
</table>
Some other considerations to keep in mind include the following:

- Even with a communication plan, institutional silos can exist (or develop) within the same agency (not even considering multiple agencies that may be part of a DPR project), leading to ineffective responses and finger pointing. As part of an integrated water management program, eliminate silos to keep the lines of communication open and cooperative.
- Too much ghost chasing can lead to skepticism (e.g. the “chicken little” syndrome without the sky falling). One solution is to sit down after an event and go thru lessons learned and make changes to the communication response plan.
- If the AWPF partner goes out looking for new CECs or lowers its monitoring method detection limits and finds CECs, it is always a good idea to let the POTW know in advance before you do this so they are prepared to respond if necessary.
- The POTWs multijurisdictional agreements may be dated and lacking “teeth” to protect a potable reuse project. The out-of-service-area partner likely has no stake in the potable reuse project and thus no incentive to be proactive or helpful in situations where one of their industries is a problem. The jurisdictional agreement will need to be updated and there may resistance to make changes. You should seek legal help and political support if this occurs.
- A facility may want to terminate the acceptance of hauled wastes at a wastewater treatment plant that provides the feed water to an AWPF because of the difficulty in preventing and finding illegal loads in hauled wastes. This action may have political ramifications particularly if the other disposal options for waste haulers are more expensive. It will be important to line up political support in advance of taking this kind of action or developing an alternative outlet for hauled waste.
- Small communities may face situations where the economy is dominated by a large industry with considerable political clout. In this situation, it will be important to bring the industry into a stewardship program during the planning process.
- If a POTW is starting from scratch (e.g., no pretreatment program), it will be critical to hire at least some staff with experience and provide training.

### 3.4.1 Risk Based Approach to CEC Prioritization

The universe of potential CECs is immense and will grow over time as analytical methods become more sensitive. As a point of reference, some potential industrial and commercial sources of CECs for DPR are noted in Table 3.3.
Table 3.3 Potential Industrial/Commercial Sources of Select CECs for DPR

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Regulatory Reference or Health Advisory Levels in Drinking Water</th>
<th>Potential Industry Sources to Municipal Wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDMA / NDMA Pre-cursors</td>
<td>California NL = 0.01 µg/L</td>
<td>¹,² Metam sodium used for root control in trunk line sewers, PCB manufacturing facilities, drum recycling facilities, Facilities using dithiocarbamate (DTC) such as metal plating facilities, carpet dye operations, printed circuit board industries.</td>
</tr>
<tr>
<td>Boron</td>
<td>California NL = 1,000 µg/L</td>
<td>³,⁴ Borax and refined borates producing facilities, agricultural herbicides and fertilizers, glass/ceramic manufacturing, soap / cleaner manufacturing, petroleum, natural gas, and shale well operations.</td>
</tr>
<tr>
<td>1,4-Dioxane</td>
<td>California NL = 1 µg/L</td>
<td>⁵ Adhesive products and membrane manufacturing</td>
</tr>
<tr>
<td>Acetone</td>
<td>EPA Reference Dose (RfD) = 100 µg/kg-d</td>
<td>⁶ Paint manufacturing, printing, laboratories, pesticide manufacturing, rubber manufacturing, etc.</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>EPA Reference Dose (RfD) = 600 µg/kg-d</td>
<td>⁷ Adhesive manufacturer, electroplating, pesticide manufacturing, paper coating, etc.</td>
</tr>
<tr>
<td>Methanol</td>
<td>CCL-4</td>
<td>⁸ Paint manufacturing, printing, laboratories, gasoline additive, etc.</td>
</tr>
</tbody>
</table>

References for Table 3.3¹ Sedlak et al., Sources and Fate of Nitrosodimethyamine and its Precursors in municipal Wastewater Treatment Plants, Water Environment Research, Volume 77, Number 1, January/February 2005. ² Woodside et al., Source Control Enhancements to foster Indirect Potable Reuse, WEFTEC 2003.

One tool that can be used to focus on prioritizing CECs for source control as well as DPR treatment is quantitative relative risk assessment (QRRA). The goal of a risk assessment is to estimate the severity and likelihood of harm to human health or the environment occurring from exposure to a risk agent (Cohrsen and Covello, 1989). A QRRA does not evaluate the absolute risk from ingestion of water “at the tap”, but rather a relative comparison based on an assumed quantity of water consumed and water quality. This methodology is based on an approach that has been used successfully for previous IPR assessments which are the basic tenants of a risk assessment. (Cooper et al., 1992, 1997 Soller et al., 2000, Soller and Nellor, 2011, a, b).

APAI (2015) conducted a QRRA for two DPR case studies. Each case study compared a No Project Alternative (raw surface water that has undergone drinking water treatment) with a potential DPR Alternative (treated wastewater that has undergone advanced water treatment and drinking water treatment). One DPR alternative included a non-reverse osmosis AWPF; the other DPR alternative included a reverse osmosis/advanced oxidation AWPF. The QRRA assessed regulated CECs. The results
were useful in evaluating the efficacy of treatment barriers as well as an approach to prioritize CECSs for source control.

Utilities in Australia are using risk assessment as a tool for control and prevention measures. Water Services Association of Australia (WSAA) has developed the Australian Sewage Quality Management Guidelines, which are a framework for effectively managing sewage discharges to a collection system from its source, through its collection, transfer and treatment, to its disposal or reuse (WSSA, 2012). The guidelines propose an approach that considers how to control risk in:

- Inputs from domestic premises,
- Rainwater inflow,
- Infiltration to sewerage systems,
- Inputs from unregulated commercial and industrial sources (e.g. illegal dischargers, premises without approval to discharge non-domestic sewage into the sewerage system etc.),
- Industrial waste,
- Tankered wastes,
- Inputs from the management of assets, and
- Decentralized or recycled water system impacts.

The guidelines provide examples and case studies for several Australian utilities.

### 3.4.2 Source Control Effectiveness

While source control is an important barrier for all potable reuse applications, there are some limitations on its effectiveness. Expectations should be realistic. Source control programs will be effective in achieving reductions or resolving problems if the following conditions exist:

- The CEC can be found at measurable levels in the POTW’s influent and collection system.
- A single industrial source or group of similar sources account for most of the influent loading and can be identified.
- The industrial or commercial discharge source can be controlled by the POTW through the regulatory process.
- The portion of the total wastewater treatment plant influent source that is identified and considered controllable must be greater than the reduction in pollutant levels needed.
- The discharge is not a “ghost” (see text box).
- There are circumstances where source control may not be effective or may have to rely on behavioral changes or legislative changes.
- POTWs cannot control the discharge of low-level radioactive wastes. These wastes are under the jurisdiction of the Nuclear Regulatory Commission and/or a delegated state agency. Some POTWs have worked with these types of industrial dischargers to voluntarily modulate how they discharge wastes to minimize impacts on the concentration of radionuclides in reclaimed water. The NRC has primacy, but if a radioactive standard exists for drinking water, a technically based local limit can be derived. It is likely this may impact the selection of the RO vs the Non-RO treatment approach. Allowable discharges into the sewer are based upon protection of the beneficial use of the biosolids and the final effluent quality. If NRC

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**Chasing Ghosts?**

A POTW may on occasion find a CECs at levels of concern and then never see it again – these events can be caused by single industrial dumps, by someone cleaning out a garage, or by an unknown source. The event will trigger action to trace it down, but may lead to an unsuccessful outcome. This kind of a situation may lend itself to the offer of a reward that may lead to a useful tip.
is not strict enough local limits can be used to ensure that the DPR water is safe and meets drinking water standards.

- POTWs cannot control residential discharges as they are not within the legal jurisdiction of POTWs. Therefore, voluntary behavioral change would have to be achieved through public outreach.
- POTWs cannot typically ban commercial products that contain CECs. To be effective, the use of a product must be restricted on a local, regional, statewide, or national basis.

### 3.5 Examples of International Pretreatment and Source Control Programs

The following presents experience in some countries outside of the US with monitoring in the collections system, all with the aim of protecting the quality of the raw sewage arriving at the WWTP and thus ensuring optimum operation of the latter.

The following describes some of those programs and additional information can be found in the Literature Compendium.

#### 3.5.1 Denmark

The City of Copenhagen is served by two WWTPs that each produce effluents of very high quality in terms of nitrogen and phosphorus suitable for discharge to the environment. Protection of the operation of these two WWTPs is a critical aim of the City’s Source Control Program.

To this end, and noting that in the biological system, the autotrophs are more sensitive to toxic upset than the heterotrophs, the City developed a mobile activated sludge plant that was based at one of the WWTPs. This mobile plant was operated at similar solids retention times (SRTs) to the two main plants and when there was evidence of a toxic upset in either plant – indicated by trends in pH, DO and blower operation – the unit would be moved to nodal points in the collection system where it would draw wastewater and evaluate the impacts on the nitrifiers. If an adverse reaction was evident, source control officers would visit the industries whose discharges went past the nodal point to take further samples (Harremoes, 1998).

#### 3.5.2 Singapore

The Public Utilities Board (PUB) in Singapore recognized this importance of source control in the early planning days of NEWater and currently has a comprehensive set of regulations in place to control industrial waste discharges to its sewers (Law, 2008) (Tan, 2008). These regulations are supported by routine surveillance and enforcement measures that include:

- Regular surveillance of industries, and particularly those identified as potential sources of illegal discharges. Identification of this latter group is achieved through analysis of licenses issued for the use of certain chemicals, the MSDS of each of these chemicals and routine analysis of industrial waste effluent;
- Routine evaluation of sewer samples from manholes at key nodes in the sewer network, and
- Regular discussion with industrial generators to educate and engage them on in-factory actions that can be taken to control or reduce their discharges.

Recognizing that the most vigilant industrial waste control program cannot prevent deliberate and intermittent illegal discharges into sewers, and as the PUB’s main concern is organic solvent discharges, it has installed Volatile Organic Compound (VOC) analyzers at strategic locations in the sewer network such as pump stations that serve clusters of industries and at WWTP inlets. The reverse osmosis permeate of the NEWater factories are also monitored for TOC as a possible indicator of increased feed...
VOC. These on-line analyzers are linked to a central monitoring system that serves as the hub of a remote VOC monitoring and warning system. In addition, transportable VOC monitoring units are used within the network and these units are complete with sampling pump such that in the event of a high vapor phase VOC being measured, a sample is taken of the liquid flow for a more detailed analysis.

An example of the effectiveness of the remote monitoring system is shown in Figure 3.2, which is a plot of VOC concentrations in effluent discharged from a factory that used an organic degreaser in its operations. Rinse waters that contained residual concentrations of this compound were discharged at night and were responsible for the high VOC levels. Discussions with the factory have resulted in an alternative alkali-based compound being used and more effective ‘house-keeping’ measures put in place.

![Figure 3.2](image)  
**Figure 3.2**  
Example of the effectiveness of the remote monitoring scheme

### 3.5.3 Australia: Real-Time Data Acquisition System for Wastewater Source Control

An integrated real-time Water Quality Information Acquisition System (WQIAS) was developed in a three-stage project over five years with funding from the Urban Water Security Research Alliance (UWSRA) in Queensland, Australia and field trials demonstrated that it is an effective management tool for wastewater source control (Zhao et al, 2012).

Stage 1 confirmed, after a detailed investigation, that current sensor technologies did not perform reliably in a raw sewage environment. Stage 2 involved the development and utilization of a sensing system that includes commercially available sensors developed for temperature, pH, conductivity, turbidity, DO and ORP, with integrated real-time event detection that operates effectively in both raw sewage and WWTP effluent.

Stage 3 involved field trials with the new sensors at the Bundamba WWTP; at Barrier 1 (the raw sewage) and at Barrier 2 (the WWTP effluent). The trials showed that the system control hardware/electronics, including the sensor platform, performed as expected, and several significant events were detected. These included several industrial waste dumps and one clarifier failure. Some of the waste dumps were shown to compromise the WWTP performance as there were notable changes in DO and pH within the biological reactor, as evidenced in the WWTP (Barrier 2) effluent.
There has been substantial interest in the project outcomes and Griffith University with four of Australia’s leading utilities (Melbourne Water, Sydney Water, Gold Coast Water and West Australian Water Corporation) are currently further developing the technology with the aim of creating a sophisticated sewer catchment management system.

### 3.6 References


CHAPTER 4.

Source Water Treatment Facility Design, Operation and Optimization for Potable Reuse

4.1 Introduction

SWTFs have been historically designed and operated to achieve a high quality effluent suitable for environmental discharge. Such end-point targets are readily achieved with a wide range of secondary and tertiary treatment alternatives. Integration of an AWPF requires a paradigm shift in the operation of SWTFs in consideration of the fact that the treated effluent is the supply water for the AWPF. Some of the principal objectives for SWTFs expanding to integrate AWP include:

- **Production of a consistently high quality supply water suitable for further treatment in the AWPF.**
  - The general characteristics of a high-quality supply water, the related impacts on the AWPF and implications for the SWTF are summarized in Table 4.1.
- **Ability to detect a poor-quality supply water and divert flow away from the AWP process.**
  - SWTFs are designed and operated to consistently achieve a high-quality effluent, however, there may be specific instances which result in production of a lower quality supply water. It is therefore important that a SWTF is able to detect the poor-quality effluent and if necessary, divert the supply water away from the AWP. Examples of poor quality effluent include: high turbidity, high DOC/TOC, high pathogen concentration, high inorganic nitrogen concentration.
- **Produce steady consistent flow**

The objective of this chapter is to provide guidance related to the impacts of the process design and configuration and operation of a SWTF on the AWPF facility. We focus here on four elements:

- **Nutrient Management.** Operation of a SWTF to produce a consistently low effluent nitrogen has the added benefit of resulting in low supply water COD and typically adequately low phosphorus levels for the supply water to be suitable for AWP processes.
- **Flow and Load Variation Management.** The flow and load into a SWTF is not usually stable and/or consistent due to diurnal variations, internal processes resulting in recycle streams and, in the case of potable reuse, recycle streams from the AWP processes. As described in Chapter 2, AWP processes are impacted by flow and load variation.
- **Sidestream Management.** Current experiences with integrating AWP with SWT processes suggest that those facilities which implement onsite solids processing may have more challenges with the AWPF. Refer to the case studies available on line at XXXXX.
- **Management of CECs.** The management of CECs in potable reuse treatment is an area of active ongoing research. Nonetheless, there is a growing body of evidence which suggests that certain CECs are more effectively removed by specific processes/unit operations than others and more efficaciously removed in processes when operated a certain way.

Note that it is not the intent of this chapter to serve as a primer on wastewater treatment or review well known operational requirements for efficient WRRF operation. The reader is referred to many excellent textbooks (e.g., Metcalf and Eddy, 2003; Grady et al., 1999), and guidance manuals (e.g., EPA Nitrogen Control Manual – EPA/625/R-93-100; 10-states standards; TR-16) on these subjects.
<table>
<thead>
<tr>
<th>Constituent</th>
<th>Impact on AWP Design &amp; Operation</th>
<th>Supply Water Recommended Target</th>
<th>SWTF Design/Operational Impacts and Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Species</td>
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</tbody>
</table>
| Ammonia-N  | • Increased MF/UF fouling and NDMA formation.  
• Increased UV/AOP system requirements | • Fully nitrified supply water (NH$_3$-N < 0.5 mg-N/L) | • Influences biological process design, control & operation  
• Requires nitrifying SRT, increased aeration demand and control, alkalinity/pH balance;  
• Where relevant benefits realized from effective management of sidestream flows/loads |
| Nitrate-N & Nitrite-N | • Health impacts of DPR water  
• May have an impact on RO design/sizing considerations  
• Significant impact on chorine demand | • Low Total Inorganic Nitrogen levels (<10 mg-N/L max) | • Incorporate denitrification in SWTF |
| Phosphorus | • Increased phosphate based RO fouling/scaling | • Low TP/OP levels | • Influences biological process design & operation  
• Incorporate biological phosphorus removal or chemical p removal  
• More significant biodegradable carbon requirements  
• Increased chemical use  
• Sludge dewatering can be more difficult  
• Increases struvite formation potential  
• Important considerations of phosphorus based biosolids land application limits,  
• If necessary, incorporate chemical phosphorus removal/polishing. For example, using (e.g., using media or membrane filtration, coagulation/flocculation and separation |
| Organic Carbon |                                   | N/A                             |                                               |
| DOC/AOC (BODs and COD as surrogates) | • Increased MF/UF and RO fouling |                                 | • May require MF/UF pretreatment such as ozone or coagulation  
• SWTF processes (primary/ biological treatment) are not designed to specifically target DOC/AOC removal  
• Target low supply water BODs and COD levels through management of biological process operating conditions (e.g. SRT, wasting, aeration) to effectively stabilize the biological process, reduce extracellular polymeric substances (EPS) and |
<table>
<thead>
<tr>
<th><strong>Solids</strong></th>
<th><strong>Turbidity</strong></th>
<th><strong>TSS</strong></th>
<th><strong>TDS</strong></th>
<th><strong>Compounds of Emerging Concern</strong></th>
</tr>
</thead>
</table>
|            | ● Increased MF/UF Fouling  
● Limits MF/UF design/operating flux | ● Low turbidity (target consistently < 2 NTU)  
● Effective management of secondary separation process | ● Increased RO feed pressure requirement  
● Increased operational costs and maintenance requirements  
● Management of the AWP recycle stream & other sidestreams (e.g., from biosolids handling) should be carefully evaluated | ● DMA and other NDMA precursors  
● Increase energy/chemical costs  
● Increase UV/AOP system requirements  
● May require pre-formed chloramines  
● Effective management of solids handling polymer use (and if practiced RAS polymer use) |
|            | ● Low TSS (< 10 mg/L) | | | ● Low (N)DMA precursors  
● Effective management of solids handling polymer use (and if practiced RAS polymer use) |
|            | | | N/A | ● Other CECs  
● Increased UV/AOP dose requirements.  
● SWTF processes (primary/biological treatment) are not currently specifically designed to treat CECs.  
● However, there is a growing body of evidence suggesting effective biodegradation, transformation and attenuation of specific CECs |
<table>
<thead>
<tr>
<th>Other Constituents</th>
<th></th>
<th></th>
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</table>
| Iron                   | • Increased RO Fouling/Scaling  
• may require optimized RO pretreatment | N/A | • WRRF processes (primary/ biological treatment) are not designed to specifically target removal of these contaminants.  
• A robust source water management program is highly recommended (c.f., Chapter 2)  
• Where iron and aluminum are used in the process (e.g., for CEPT) effective monitoring and periodic (re)evaluation of target dose (using bench scale testing) is highly recommended. |
| Manganese              | • Increased MF/UF Fouling  
• MF/UF pretreatment may be required  
• Limit MF/UF design flux | N/A |  |
| Aluminum               | • Increase RO fouling/scaling  
• may require optimized RO pretreatment | N/A |  |
| Silica                 | • Increase RO fouling/scaling  
• may require optimized RO pretreatment including antiscalant addition and pH adjustment | N/A |  |
| Residual Coagulant/ Polymer | • Increase MF/UF Fouling;  
• Increase NDMA Formation | N/A | • Effective management of solids handling polymer use (and, if practiced, RAS polymer use)  
• Effective management of coagulant use (e.g., for CEPT) |
4.2 Nitrogen Management

4.2.1 Overview of Nitrogen Removal
Nitrogen removal in a WWRF is conventionally implemented using biological nitrogen removal processes – where organic or inorganic nitrogen is converted to nitrogen gas. Biological nitrogen removal is achieved through a multi-step process. Ammonia is oxidized to nitrite (via hydroxylamine) by ammonia oxidizing bacteria (AOB); nitrite is oxidized to nitrate by nitrite oxidizing bacteria (NOB); these steps occur under aerobic conditions. The nitrate is subsequently reduced to nitrogen gas by denitrifying bacteria (DNB) under anoxic conditions (see Figure 4.1, top panel). The oxygen required by AOB for nitrification, is typically provided to the biological process by pumping air via diffusers in the aerobic zones. The denitrification process requires organic carbon as the electron donor.

In recent years, nitrogen management employing partial nitritation (i.e., conversion of ammonia to nitrite) coupled with anaerobic ammonium oxidation autotrophic nitrite reduction (anammox) has gained significant popularity for both sidestream and mainstream processes (Figure 4.1, bottom panel). The primary drivers are the substantial reduction in oxygen requirements to achieve low TN levels and the complete elimination of supplemental carbon requirements for denitrification. On the other hand, anammox bacteria have a slow growth rate relative to AOB and therefore the reactor may require more volume. Note that with anammox retention strategies such as the use of sieves and hydrocycles, the required volume is reduced. Utilities should carefully evaluate the most effective and appropriate technologies and process configurations to achieve the target supply-water nitrogen target indicated in Table 4.2.

Figure 4.1 (Top Panel) Conventional biological nitrogen removal relying on ammonia oxidation to nitrate (i.e., nitrification) and nitrate reduction to nitrogen gas (i.e., denitrification). (Bottom Panel) Deammonification process integrating partial nitritation and anaerobic ammonium oxidation with autotrophic nitrite reduction
4.2.2 Biological Process Technologies

Biological treatment unit operations and technologies to achieve nitrogen removal can be grouped into three broad categories: suspended growth systems (containing bacteria in floc), hybrid systems (containing both floc and a biofilm) and fixed film processes (consisting of only biofilms and no suspended floc). Some typical examples of such processes are shown in Figure 4.2.

4.2.3 Biological Process Configurations

The selection of the process configuration used to achieve nitrogen removal (e.g., Modified Lutzak-Ettinger (MLE) process or Bardenpho process) is dependent on the effluent quality target as illustrated in Figure 4.3.

4.2.4 Optimizing Nitrogen Removal

A summary of guidance for WRRFs to manage and optimize nitrogen removal is provided in Table 4.2.
<table>
<thead>
<tr>
<th><strong>Factor</strong></th>
<th><strong>Impact</strong></th>
<th><strong>Comments/Recommendations</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solids Retention Time (SRT)</strong></td>
<td>SRT may be considered a master process control variable when considering COD and nutrient removal. Note that, as discussed in more detail in Section 4.4, SRT is not a functional master variable when considering CEC removal. Inability to operate at the appropriate SRT (which depends on temperature, reactor DO, etc.) will limit the ability of a SWTF to consistently meet the nutrient targets.</td>
<td>The SWTF biological process should be designed at the appropriate SRT to achieve complete nitrification and effective denitrification to meet the target Total Inorganic Nitrogen target. To consistently operate at a target SRT, it is recommended that the mixed liquor separation process (e.g., clarifier or membrane filter) should be designed to adequately accept the solids loading corresponding to operation at the full range of SRTs required throughout the year. Where viable, a SWTF should consider implementation of SRT/inventory management program using realtime process controllers or through operator control (for an example of the benefits of SRT control – see Figure 4.4 in the Illustrative Example). General Recommendation: SWTFs should develop and manage a dynamic process model (using any of the commercially available process simulators) to assess and optimize nutrient removal. The model can also be used to evaluate process operation strategies considered.</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>Temperature impacts biokinetics and nitrification/denitrification efficiency</td>
<td>SWTFs have no control of the water temperature. However, it is important that the process design consider treatment of the influent at the full range of typically experienced temperatures. The designer should extensively analyze the influent (and where available and relevant primary effluent) temperature and utilize short term (e.g., 3, 5 or 7-day) rolling average temperature as the basis of design. Operators should carefully monitor influent and (where applicable) primary effluent temperature and make process changes based on the measured values. Where temperature trends are well understood, operators should utilize predictive process management approaches to develop operating strategies for the SWTF in anticipation of upcoming events.</td>
</tr>
<tr>
<td><strong>Factor</strong></td>
<td><strong>Impact</strong></td>
<td><strong>Comments/Recommendations</strong></td>
</tr>
<tr>
<td>------------</td>
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</tr>
<tr>
<td>Inhibitory substances in the biological treatment process</td>
<td>Inhibitory substances impact nitrification/denitrification efficiency. Or, in extreme cases, may result in complete process failure.</td>
<td>As discussed in Chapter 2, implementation of a rigorous source control program is an essential component of a successful potable reuse program. Certain metals (e.g., nickel, copper, and zinc), pharmaceuticals and other compounds are known AOB inhibitors. A robust source control program is invaluable to reduce the risk to the biological process.</td>
</tr>
<tr>
<td>Reactor Dissolved Oxygen Concentration</td>
<td>The DO level in the reactor has a strong impact on the biological process occurring. BOD removal and nitrification typically require aerobic environments, whereas denitrification requires an anoxic environment.</td>
<td>For nitrification - the reactor DO should be maintained at a level so as not to limit the nitrification efficiency. However, where SWTFs implement Simultaneous Nitrification-Denitrification (SND) to achieve Total Nitrogen Management (Diagger and Littleton, 2014), plant operators need to be manage the reactor DO to balance nitrification and denitrification activity in the same zones. For denitrification – the DO in the anoxic zones should be zero. The design of the process should avoid use of overflow weirs with a freefall into an anoxic zone. Where MBRs are used, a deoxygenation zone (or other approaches) should be integrated to ensure uptake of the DO in the RAS. Mixing chimneys should be used to introduce the influent return active sludge, and internal recycle flows into the anoxic zone. This will allow for minimal mechanical mixing to avoid excessive oxygen entrainment. It is recommended that SWTFs implement automated aeration control using a suite of online sensors for DO. To enhance the overall sustainability of the SWTF (and potable reuse implementation) ammonia based control can also be included to manage the aeration (Reiger et. al., 2014). In addition, it is recommended that integration of swing zones be incorporated into the SWTF design, where possible.</td>
</tr>
<tr>
<td>Availability of Carbon for Denitrification</td>
<td>Carbon in required for denitrification. Insufficient biodegradable carbon will severely limit the denitrification efficacy.</td>
<td>Where the soluble BOD/TKN ratio of the influent to the biological process is too low to support effective and consistent denitrification supplemental carbon must be provided. Several options are available to provide supplemental carbon. Recommended options include: Purchase of supplemental carbon in the form of methanol, glycerol or a proprietary chemical (e.g., MicroC);</td>
</tr>
<tr>
<td>Factor</td>
<td>Impact</td>
<td>Comments/Recommendations</td>
</tr>
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<td>----------------------------------------------</td>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Implementation of primary sludge fermentation (or active primary clarification) to produce soluble COD which may be directed to the biological process; Implementation of mixed liquor fermentation (Keller et. al., 2011; Barnard et. al., 2015) Note that the carbon source will have an impact on denitrification rate in the biological process (Phillips, et. al., 2010). Utilities should carefully evaluate the inclusion of primary or advanced primary treatment ensuring sufficient organic carbon is consistently available in the biological treatment process.</td>
<td></td>
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</tr>
<tr>
<td>Availability of alkalinity for nitrification</td>
<td>Alkalinity is required for nitrification. Insufficient alkalinity will severely limit the nitrification efficacy.</td>
<td>Alkalinity can be supplied using a wide array of chemicals. When considering potable reuse, it is recommended that the quality of the chemicals is evaluated for potential impurities additive or inert component which may impact the AWP (e.g., iron, manganese, etc.)</td>
</tr>
</tbody>
</table>
Illustrating the Benefits of Effective SRT Management on Supply Water Ammonia Concentration

A facility operating a successful non-potable reuse (Title 22 effluent) program implemented a more stringent SRT/solids inventory control program in 2015. Shown in the top panel of Figure XX below are the calculated daily SRT during 3-month period (September to December) prior to (2014) and with (2015) implementation of an SRT management approach. Also, shown is the effluent ammonia nitrogen concentration during the same period in 2014 and 2015. In 2014, the effluent ammonia concentration during this 3-month period was highly variable ranging from 2 to approximately 20 mg-N/L. In contrast, during the same period in 2015, the effluent ammonia nitrogen concentration was consistently below 0.5 mg-N/L.

![Graph](image-url)

Figure 4.4 (Top Panel) Calculated Daily SRT for a Biological Treatment Process Currently Implementing Non-Potable Reuse in Sep-Dec 2014 and 2015. (Bottom Panel) Effluent ammonia concentration for the same time period
4.3 Managing SWTF Process Flow and Load Variability

4.3.1 Resulting from SWTF Influent Flow and Load Variation

- A number of SWTFs experience diurnal flow variation which can be as much as a 100% difference or more between the high flow and low flow periods. The diurnal variation effects are exacerbated in smaller facilities.
- There are however also several treatment plants which have the ability to maintain a constant flow as other downstream facilities are available to treat the balance of the flow (i.e., sewer mining).
- In addition, there are typical diurnal variations in the influent pollutant concentration (e.g., Martin and Vanrolleghem, 2014).
- Where reliable data are available, it is recommended that the WRRF design/optimization utilize the diurnal pattern for both influent flow and pollutants concentration. This will enable a more accurate estimation of the pollutant mass load going into the SWTF, which is the critical parameter.
- Where reliable diurnal data are unavailable:
  - Techniques are available to generate synthetic data to simulate the diurnal pattern (Langergraber et al., 2008; Langergraber et al., 2009) in a plant process/optimization model;
  - It is also recommended that the SWTF implement a special sampling campaign to characterize the variability in (i) influent flow, (ii) pollutants concentration in the plant influent and biological process influent (if different), (iii) recycle flows and pollutants concentration. At minimum, the analyses should include conventional pollutants (e.g., COD fractions, TKN and inorganic nitrogen species, phosphorus, alkalinity, pH, etc.) but SWTFs may also consider analyzing the variation in the concentration of pathogens and CECs.

4.3.2 Flow and Load Variability Resulting from In-Plant Recycle Streams

- Many SWTFs include solids processing (e.g., anaerobic digestion followed by dewatering) operated for a portion of the day. In such systems, the recycle flows within the plant are intermittent. Other facilities include continuous (i.e., 24 h/d, 7d/week) solids processing. In these cases, the contribution of the recycle stream can be highly variable during the day resulting in fluctuating oxygen requirements and potential process instabilities during the day.
- Although these streams contribute only a small percentage to the flow into the biological process, the related load contribution can be quite significant (e.g., 20% - 30% of the load to the process.)
- We emphasize here the importance of pollutant load recycling within a plant.
- A range of technology/process approaches are available to manage these flows as discussed in more detail in Section 4.5.
4.3.3 Using Equalization to Minimize Flow/Load Variation into the Biological Process

- Flow and load variations into the biological process can be significantly dampened (or eliminated) using influent flow equalization (for a detailed discussion of flow equalization strategy, guidelines and design, c.f., Metcalf & Eddy, 2003)
- This approach however, is not without its drawbacks, which include:
  - Increased potential for hydrogen sulfide production. This necessitates active management of the equalization tank/system.
  - Increase in odor potential. This could be managed to some degree by equalization of flow following primary treatment.
  - Increased operations and maintenance requirements. Either online or offline equalization tanks and systems need to be regularly maintained and the assets need to be effectively managed.

4.3.4 Using Equalization to Minimize Flow/Load Variation from the Biological Process

- Additional equalization may be needed ahead of the AWPF.
- The sizing of AWP processes is typically driven by hydraulics; equalization may be a low-cost solution to manage flow variation.
- This is particularly beneficial for AWP maintenance where trains are taken in and out of service.

4.4 CEC Removal

4.4.1 CEC Removal in Primary Treatment Processes

A limited number of studies have evaluated the removal of CECs in primary treatment wastewater processes. Since primary treatment is essentially a particle removal process, CECs removed would generally be bound, or entrained within, particles. Thus, substances that are hydrophobic tend to bind to organic particles and can be well removed within primary processes. For instance, the removal of CECs in both conventional and enhanced primary treatment is extremely variable, ranging from less than 1% total removal to greater than 90% (Carballa et al., 2005; Suarez et al., 2009; Zorita et al., 2009).

Sorption is thought to be the dominant mechanism for CEC attenuation in primary treatment (Carballa et al., 2005; Stackelberg et al., 2007) with lipophilic compounds removed to a greater extent. The addition of a coagulant in bench tests improves the removal of PhACs and PCPs (Carballa et al., 2005).

In general, primary treatment should not be considered a significant barrier for the vast majority of CECs.
4.4.2 CEC Removal in Biological Treatment Processes

In recent years, there have been a number of excellent reviews of CEC removal in biological treatment processes (e.g., Kagie et al., 2009; Onesios et al., 2009; Oulton et al., 2010). In addition, the United States EPA has developed and maintains a comprehensive database of CEC removal for a wide range of treatment process and full-scale systems in both water and wastewater treatment plants and experimental systems (United States Environmental Protection Agency, 2010).

A consistent theme across individual studies and broader reviews is the significant variability observed in CEC removal during biological treatment. Sathyamoorthy, 2013 reviewed the removal of pharmaceuticals in biological treatment processes and found that the reported removals of 51 pharmaceuticals varied from 0% (e.g., for carbamazepine) to almost complete removal (e.g., naproxen and ibuprofen). CEC removal efficiency in the biological treatment process depends on several factors, including unit operation type (e.g., suspended growth vs. fixed film) and configuration, mixed liquor concentration, solids retention time (SRT), hydraulic retention time (HRT) and CEC properties (Ternes et al., 2004; Joss et al., 2006; Stephenson and Oppenheimer, 2007; Oulton et al., 2010).

4.4.2.1 Importance of SRT in CEC Removal

- The SRT required for CEC removal has received significant attention in recent years.
  - European Union’s Poseidon project indicated improved CEC removal in WWTPs operated at long SRTs (≥ 8 10 days) (Kreuzinger et al., 2004; Ternes et al., 2004; Clara et al., 2005; Joss et al., 2006). And, numerous follow up studies have suggested and/or observed a link between PhAC removal and SRT in WWTPs.
  - Suarez et al. (2012), for example, suggested that the removal of the pharmaceutical sulfamethaxazole increased from 38% to 63% 70% when the SRT of a suspended growth MLE pilot process was increased from <20 to >40 d. However, in this study, a longer SRT had no impact on the removals of other pharmaceuticals including carbamazepine and diazepam.
  - Schroder et al. (2012), studying pharmaceutical removal in two parallel MBRs operating at SRTs of 15 and 30 d, reported improved removal rates for sulfamethoxazole among other pharmaceuticals but no improvement for others, including ketoprofen and naproxen.
  - Gerrity et al. (2013) operated different basins at a single treatment plant at different SRTs ranging from 5.5 – 15 days and found that operation at a longer SRT was beneficial for attenuation of some, but not all CECs. steroid hormones and some other efficiently attenuated substances, removal was nearly complete at 5.5 days and increasing SRT was not of added value.
  - Improvements in CEC removal have been suggested to be linked to a wider bacterial diversity (Gobel et al., 2007) or the higher concentration of slow growing bacteria essential for CEC biodegradation and removal (Reif et al., 2008)
  - Despite the attention given to the possible link between SRT and PhAC removal, the correlation is not accepted by all researchers. Majewsky et al. (2011) argued that long SRTs would reduce the removal efficiency of sulfamethoxazole and diclofenac as attenuation results primarily due to heterorophic bacteria (HET) and an increase in SRT would decrease the active HET.
  - Furthermore, several studies have reported that certain CECs, such as carbamazepine (CBZ) and diclofenac (DCF) are poorly removed even at very long SRTs in both suspended growth and MBR systems (Clara et al., 2005; Nakada et al., 2006; Radjenovic et al., 2007; Xue et al., 2010; Majewsky et al., 2011).
  - Clara et al. (2005) and Stephenson and Oppenheimer (2007) suggested the utility of a critical SRT, defined as minimum SRT which provides a predetermined removal of the CEC, to classify the removal of CECs While there may be debate related to what such a predetermined level should be such an approach provides a uniform basis to evaluate CEC attenuation. In addition,
the use of SRT as a master control variable for CEC removal is attractive to the WWTP design and operations community as it provides a specific and achievable target.

- One drawback of this approach from an environmental impact standpoint is that it fails to account for the potential impact of biodegradation metabolites produced in the treatment processes. This may prove particularly important considering studies which have shown increasing ecotoxicity along degradation pathways (Isidori et al., 2005). Further, while this approach provides a measure for the extent of attenuation of the parent CEC and minimum SRT required to achieve the removal benchmark, it provides limited process design relevant information (e.g., process configuration, redox conditions, and degradation rate).

### 4.4.2.2 Comparison of CEC Removal in MBRs and Conventional Biological Processes

Numerous studies have evaluated CEC removal in MBRs or experimentally compared CEC removal between suspended growth (SG) systems and MBRs. A direct comparison of the two processes however is made complicated by the fact that these processes are typically not operated at similar conditions which influence CEC attenuation. Comprehensive operating data are not often reported in full-scale studies making it extremely difficult to find identical operating conditions for suspended growth and MBR processes. Or, when the data are provided, MBRs are often operated at significantly higher MLSS and typically longer SRTs than the suspended growth system making side-by-side comparisons complex. To illustrate this point – shown in Figure 4.5 is a simplified distribution of CEC removal from a longitudinal evaluation of an aggregated data set consisting of 51 pharmaceuticals from over 30 full scale SWTFs and lab/pilot scale studies (from Sathyamoorthy, 2013). A quick review of this Figure might suggest that MBRs are better suited for CEC removal (e.g., median removal rates are higher). To overcome some of the challenges related to a direct comparison, Sathyamoorthy, 2013 analyzed a subset of these data, using SRT as a surrogate measure for operating conditions and compared CEC removal in SG and MBR processes operated at similar SRTs (Figure 4.6). Evaluation of these data indicates that CECs which are removed to a great extent in suspended growth systems are also effectively removed in MBRs. MBRs, therefore, offer no significant advantage for CEC removal. Taken together, three key considerations - relevant to CEC removal - when selecting a process/technology for biological treatment are: (i) CEC removals are highly variable for both suspended growth and MBR systems; (ii) there remains a diverse range of opinions regarding the benefits of MBRs versus suspended growth systems for CEC removal, however; (iii) the process type does not have a statistically significant impact on pharmaceutical removal when these processes are operated at similar conditions.
Figure 4.5  Distribution of pharmaceutical (PhAC) removal in suspended growth and membrane bioreactor processes in full scale WWTPs. There are a total of 259 data points (suspended growth – 175, membrane bioreactor – 84). Median values for each data set are indicated. Also shown in the distribution of removal for all data from full scale WWTPs and bench scale studies as a single data set (inset) - there are a total of 293 data points here (Figure from Sathyamoorthy, 2013)
Figure 4.6 Comparison of PhAC removals in suspended growth (CAS) and MBR systems. Data shown are average of reported removals for PhACs where data are available. Where available, data are also shown as a function of SRT. Also shown (background) are averages of all data (independent of reported SRT) (Figure from Sathyamoorthy, 2013)

4.5 Management of Sidestream Flow and Load

Onsite management of waste solids at a WRRF results in the production of recycles, collectively called sidestream (flows), which are returned to the main stream process. Some conventional approaches for management of these sidestream flows included:

- Equalization to allow for balanced return flow and loads
- Return of these flows upstream of the biological process (either to the plant influent or mixed with the primary effluent) as they were generated through operation of solids handling processes such as thickening and dewatering.
- Blending some of the sidestream with the return activated sludge (RAS) with the remainder returned into the mainstream flow. Note that this is specific to RAS nitrification; there are a range of patented process which achieve a similar result (i.e. return of less ammonia-Nitrogen with some nitrite-N and nitrate-N to the mainstream process).

Over the last one to two decades however, management of the sidestream flow has become commonplace at a number of SWTFFs because of the benefits, which include:

- Reduction in the nitrogen load to the mainstream (the nitrogen load can be as high as 40% in some plants);
- Cost effective nature of treatment options for the small flow/high load nature of the return streams that allow for lower energy, carbon, and alkalinity supplementation; and
- The potential to beneficially recover nutrients from the sidestream

A brief description of management options for sidestreams is provided in Table 4.3.
<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Brief Description</th>
<th>Comments/Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow/Load Balancing</td>
<td>The sidestream load is stored in an equalization tank and fed at a controlled rate into the mainstream process.</td>
<td>Though not a treatment option, this approach can have tremendous benefits in alleviating nutrient load fluctuations into the biological process which will result in more stable and consistent operation. The equalization tank can be sized using a load-balancing approach or a flow-balancing approach. In either case, the planner/designer should account for any extended high-load events a plant may experience during the year (e.g., over a long weekend, etc.) and determine the best sizing strategy to maximize resource allocation. Like any other equalization tank, the design and operation should incorporate effective tank maintenance and management strategies (cleaning, equipment maintenance, equipment/system redundancy, etc.).</td>
</tr>
<tr>
<td>Nitritation/Denitritation</td>
<td>Ammonia-nitrogen in the sidestream is converted to nitrite-nitrogen (i.e., nitritation), which is subsequently converted to nitrogen gas (i.e., denitritation). Examples of this include: the Stable and High Activity Ammonia Removal Over Nitrite (SHARON) process (Hellinga et. al., 1999, Kempen et. al., 2005) and the STRASS process (Wett and Rauch, 2003) Bioaugmentation Batch Enhanced (BABE®) and others</td>
<td>The process functions through the selection of AOB over NOB in the reactor. At the high temperature of the sidestream (~30-38 oC), this is achieved using a short SRT (typically &lt; 2 days, with approximately 60% aerobic and the remainder anoxic). DO control (typically 0.3 - &lt;2 mg/L) and management of supplemental carbon for the denitritation step are important operational aspects and must be well understood and feasible for operations staff. There are several operational SHARON systems worldwide. The ammonia-N concentration in the SHARON influent at these facilities ranges from 700 – 1,500 mg-N/L and they typically achieve &gt;85% removal through the SHARON process. SWTFs evaluating the SHARON for sidestream treatment should consider a knowledge exchange with these operational facilities in order to comprehensively evaluation implementation at their facility.</td>
</tr>
<tr>
<td>Management Strategy</td>
<td>Brief Description</td>
<td>Comments/Recommendations</td>
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<tr>
<td>Deammonification</td>
<td>These processes rely on AOB to convert a portion of the ammonia-N to nitrite-N, which, in addition to the remaining ammonia-N, is utilized by Anammox bacteria to produce nitrogen gas.</td>
<td>There have been several successful pilot and full scale applications of deammonification in the last decade. A range of commercial deammonification processes are now available (see below).</td>
</tr>
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<tr>
<th></th>
<th>AMX-BBF</th>
<th>Anammox®</th>
<th>ANITA Mox</th>
<th>Cleargreen</th>
<th>DEMON</th>
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<tr>
<td>Reactor Config.</td>
<td>BAF</td>
<td>Upflow CSTR</td>
<td>MBBR</td>
<td>SBR</td>
<td>SBR with hydrocyclone</td>
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<td>Process Config.</td>
<td>fixed-film</td>
<td>Biofilm granules</td>
<td>fixed-film</td>
<td>suspended growth</td>
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<td>Vendor/Technology Provider</td>
<td>BKT</td>
<td>Paques</td>
<td>Veolia</td>
<td>Suez</td>
<td>World Water Works</td>
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</table>

SBR based anammox processes have been the most popular – comprising roughly 80% of full scale installations since ~2000 (Lackner et. al., 2014). Some of the key process management factors which should be incorporated include: DO control, SRT control, alkalinity requirements, washout and out-selection of NOB. And, some of the key operational factors which should be considered include: maintenance, calibration and/or failure of mechanical and instrumentation systems.

There is a substantial knowledge base for side-stream anammox applications as of the writing of this guideline (2016) and pilot trials to demonstrate proof of concept are not warranted. However, SWTFs considering implementation of anammox based processes for sidestream stream as part of a broader program for DPR should, at minimum, consider:

- Site visits and knowledge exchange with SWTFs who have implemented deammonification. Preferably with an operations/maintenance staff profile similar to their own. This will provide an opportunity for knowledge exchange related to day-to-day considerations.

- Internal and external operator training and development of “Process Champions” who will be the primary disseminators of knowledge and information related to anammox implementation (i.e., anammox Subject Matter Experts – SMEs), management and operation at the SWTF.
4.6 References


Stephenson, R. and J. Oppenheimer (2007). Fate of Pharmaceuticals and Personal Care Products Through Municipal Wastewater Treatment Processes, WERF.


CHAPTER 5.

Source Water Treatment Facility Process Monitoring and Control

5.1 Introduction

Chapters 3 and 4 have examined the impact of source water control and source water treatment strategies on the quality and variability in the supply water. An important element of DPR is the transition of a conventional WWTF into a SWTF; this has also been emphasized in the preceding Chapters. There is a twofold implication of this:

- Target Effluent Quality. Conventional WWTPs are designed, operated and regulated to meet environmental water quality targets. In the United States, this falls under the umbrella the Clean Water Act and is intended “to restore and maintain the chemical, physical and biological integrity of the Nation’s waters”. Water quality requirements under a facility's NPDES permit alone may not be sufficient to provide a reliable DPR Supply Water.

- Variability of Effluent Quality. Meeting environmental discharge targets (e.g., stream or ocean discharge) typically affords some flexibility in the effluent quality. While this flexibility is undoubtedly a benefit for operation of conventional WWPTs, it may be an impediment for successful DPR implementation. Indeed, the variability in the effluent quality of conventional WWTPs is one of the challenges in widespread implementation of potable reuse. This is a particular concern in DPR applications in light of the shortened response time between Supply Water and Drinking Water relative to IPR.

Robust and reliable process control and monitoring are important SWTF management tools which would enable the production of a consistent effluent quality with limited variability. The objective of this chapter is to review strategies and options to monitor and control SWTF to manage, minimize and mitigate the risks associated with SWTF process upsets and/or deviations which would have a detrimental impact on the supply water quality or production consistency. Note that the strategies presented here may be equally beneficial to WWTPs which are not SWTFs.

5.2 Instrumentation for Process Monitoring and Control

5.2.1 Use of Online Instruments in Source Water Treatment Facilities

The supply water quality is measured and monitored using a combination of online and bench analyses. Therefore, effective management of these tools is essential to a successful DPR program. There are a wide array of instruments and related monitoring or control applications regularly used in SWTFs – ranging from real time source water pH monitoring to online ammonia N and DO measurement in the biological process to control air delivery. A brief overview of the process measurement and monitoring instrumentation applicable across different treatment stages of a SWTF is provided in Table 5.1. It is important to note that all these analyzers have been in use at SWTFs for an extended period of time and site-specific evaluation may not be warranted. However, the importance of maintaining a consistent delivery and quality of supply water increases the importance of instrumentation and process monitoring within the SWTF.
Shown in Figure 5.1 is a process block diagram for a typical SWTF using primary clarifiers with biological nutrient removal to achieve biological treatment (BOD removal, nitrification, denitrification). The SWTF includes offline flow equalization of the primary effluent and in-line flow equalization for the biological process effluent. Both these equalization tanks are multi-compartment tanks where the influent can be directed to a single isolatable compartment. The Supply Water from this facility can be sent to the AWPF or to a receiving body. Both primary sludge and waste activated sludge are stabilized through anaerobic digestion, dewatered and composted at this SWTF. Digester gas is used in a combined heat and power process (not shown for clarity). Recycles from the AWPF (for example RO concentrate and MF/UF backwash waste) are returned to the flow equalization tank upstream of the primaries along with sidestream from the solids handling facilities (thickening and dewatering).

The guiding process objective for this facility is to produce a Supply Water with a low turbidity and Total Inorganic Nitrogen (i.e., NH₃ + NO₂ + NO₃) in the most consistent manner possible. Using this as a basis, operations staff can develop process operating, control and monitoring strategies and the requisite level of instrumentation. Shown in the Figure are a suite of composite samplers and instruments utilized to implement the process strategy. Some of the key elements of this strategy germane to potable reuse, including the instrumentation used to achieve it, are discussed below.

- The Supply Water (Stream ID F16) TOC, turbidity, ammonia, nitrite, nitrate and conductivity are monitored using online instrumentation. A 24-h composite sample is also collected of the Supply Water.
  - When the turbidity, ammonia N or NOx-N (NO2+NO3) are greater than the maximum permissible level (see Section 6.2 for more details on this concept), the Supply Water is diverted to the receiving water body. Note that not shown in the Figure are process control interlocks with the AWPF. For example, Supply Water can also be diverted to the receiving body if/when the finished water demand is reduced.
  - Supply Water TOC and conductivity are only monitored (not used for control) and this information can be used as part of an Integrated Decision Support Tool to help the AWP operator effectively manage AWP cleaning and/or equipment standby/offline status. Note that analysis of long-term monitoring data will enable plant staff to discern any patterns in Supply Water TOC (e.g., linked to solids-handling processes operation or AWP recycles) and make operational changes to enhance the Supply Water Treatment Process (e.g., through changes in polymer use/selection) and mitigate any risks this may pose to the AWP.

- Ammonia, nitrite, nitrate, suspended solids, pH, DO and ORP are monitored using online instrumentation in the Biological Nutrient Removal Process (Process Unit-6 (PU-6)).
  - SS, NH3-N, DO, ORP and pH are used for process control (aeration and supplemental alkalinity chemical addition) to minimize the energy required for biological treatment.
  - SS, NH3, NO2 and NO3 of the BNR-effluent are also used to control the destination of the biological process effluent. If/when any of these parameters exceed the critical or maximum limits, the effluent is directed to a particular compartment of the downstream equalization tank, which can be isolated from the rest of the EQ tank and independently directed the outfall, if desired (NB: this level of detail is not shown in the Figure for clarity). Alternatively, this column can be stored and subsequently mixed with a higher quality effluent and used as DPR Supply Water. This operation can be pre-programmed for execution in the SCADA system. Or this logic can be pre-programmed to issue an operator alert at a particular time in the settle phase (e.g., 15 min before the end of settle) and the operator will have to execute the operation. This is a decision which must be made by the utility i
Table 5.1 Potential Process Instrumentation, Monitoring and Control Tools for SWTF Unit Operations

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</table>
In consideration of staffing levels, staff knowledge-base and other site specific considerations.

- COD, ammonia and pH are monitored in the Primary Effluent (F11) and Influent (F5) using online instrumentation. A 24-h composite sample of both streams is also collected.
  - The Primary Effluent NH3 N is used in the aeration control algorithm in the biological process and/or to control swing zone assignment to increase or decrease aerobic or anoxic SRT.
  - Influent and Primary Effluent NH3 N are used to manage the pumps in the influent flow equation tank (PU-4) as part of a load-based approach to return recycle flows into the main stream.
  - Primary effluent COD alert levels are utilized to monitor and assess primary clarifier performance. A database on performance and alert/alarm levels are developed as part of the plant commissioning effort (and modified periodically by the subject matter expert(s) (SME(s)), as needed).
- Ammonia, pH and ortho-P are monitored in both recycle streams: AWP Recycle (F18) and Solids Handling Recycle (F33) using online instrumentation. In addition, TDS and conductivity are monitored in F18, while COD is monitored in F33.
  - The recycle streams NH3-N are used to manage which equalization compartment the flow should be stored in and to manage the pumps in the influent flow equation tank (PU-4) as part of a load-based approach to return recycle flows into the main stream (in conjunction with the NH3-N measurement in the influent and primary effluent.

Even a cursory review of the abridged process operations strategy described above clearly illustrates the demands placed on automation and process control in a modern SWTF. Therefore, a comprehensive instrument management plan is critical for successful plant operation. This is described in the next section.
Figure 5.1  Example of plant-wide process monitoring at a SWTF producing DPR Supply Water
5.2.2 Comprehensive Instrumentation Management Plan
Use of online instrumentation has tremendous benefits for operations staff. However, the utility of the instrumentation (and related data) is only as good as the quality of the sensor and information generated. It is therefore recommended that the SWTF develop, manage and maintain a Comprehensive Instrumentation Management Plan which incorporates, at minimum, the elements listed in Table 5.2 for each instrument at the SWTF.

Table 5.2 Components of a Comprehensive Instrumentation Management Plan

<table>
<thead>
<tr>
<th>Basic Information</th>
<th>Location, Tagging Information, Manufacturer, Model, Year Purchased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Measured parameter, process function, control function, derived calculations</td>
</tr>
<tr>
<td>Process Criticality</td>
<td>Level of importance to maintaining process function and integrity. Use a ranking system (e.g., 1 = monitoring only – no impact on process; 5 = critically important – cannot operate process without it)</td>
</tr>
<tr>
<td>Calibration and Validation Information</td>
<td>Calibration requirements, Calibration log (with date completed, operator/technician name, calibration summary)</td>
</tr>
<tr>
<td>Maintenance Information</td>
<td>Instrumentation checks required (with frequency, e.g., daily, weekly, monthly, etc.), Maintenance Log (with date completed, operator/technician name, check or repair summary)</td>
</tr>
<tr>
<td>SWTF Subject Matter Experts</td>
<td>Applicable for complex instrumentation and/or instrumentation utilized for process control functions</td>
</tr>
</tbody>
</table>

5.3 Performance Monitoring for Pathogen Control
The most widely used surrogate parameters of microbial quality management are disinfectant residuals, filtration performance as measured by turbidity or particle counts, and measurements of group microbial parameters such as total coliforms, E. coli and fecal coliforms, coliphages, and other microbial indicator organisms. Other surrogate parameters specific to process performances include ultraviolet light transmission and membrane performance parameter tests.

Total coliforms, E. coli and fecal coliforms are the most common indicator culture tests for microbial water quality performance. Each relies on their presence in sewage in large numbers greater than other bacterial and viral pathogens, their equivalent sensitivity to disinfectants and reduction by disinfection and other treatment processes, their ease of measurement. Water quality goal values are less than 1 per 100 ml of water sample. A larger sample would have greater sensitivity. They require on the order of 16 to 24 hours of culture time so these tests cannot be used as real time performance systems. The most commonly used indicator test for viruses is MS2 coliphage.

5.4 Performance Monitoring for Chemical Constituents
5.4.1 Chemical Monitoring Strategies
Source waters and the supply water for the AWP can potentially contain a wide array of chemical substances originating from commercial inputs, naturally occurring chemicals, or a nearly infinite number of transformation products from both synthetic and endogenous chemicals. Monitoring for every potential chemical substance is not feasible. Thus, a surrogate and indicator approach is warranted where a shortlist of meaningful indicator chemicals is routinely monitored and more rigorous toxicity assessment may be conducted more infrequently (Anderson et. al., 2010; McDonald et. al.,...
2015; Snyder, 2014). Importantly, a sound selection framework is needed that can provide a short list of meaningful indicator chemicals that can address (i) human health risks, (ii) efficacious performance of treatment processes, and (iii) requisite compliance with guidelines and/or regulations. In addition, suitable surrogate parameters are identified which are utilized to monitor the performance of unit processes. These surrogate parameters can and should be monitored at a high frequency using online instrumentation and should have sufficient granularity to enable detection of potential changes. Example surrogates including UV transmission, total organic carbon, conductivity, and chlorine residual. Surrogates can allow for near real-time decision making for process control while chemical indicators will most often be analyzed by off-line analyses that may require several days for analysis.

A previously published WateReuse Research Foundation report (Drewes et. al., 2008) offered suggestions for additional monitoring frequency during initial start-up (pilot testing and/or commissioning) and full-scale operations (Table 5.3). During pilot testing and/or initial start-up, it is important to conduct validation testing to ensure that the system is operating as designed. Once stable conditions have been reached, the monitoring program consists primarily of operation (surrogates) and verification (indicators).

One mechanism to more comprehensively evaluate the occurrence and attenuation of chemicals in potable reuse systems is to conduct non-targeted analysis to better elucidate tentatively identified compounds (TICs). Today, the most common tool for non-targeted analysis is mass spectrometry, which can identify substances based on a mass to charge ratio (M/Z). Most often, chemicals must be extracted and concentrated from the water samples prior to analysis. Organic chemical analyses are roughly split into volatile, semi-volatile, and essentially non-volatile species. Generally, a separation process using either gas chromatography (GC) for volatiles or liquid chromatography (LC) for lower volatility species will be applied prior to introduction into a mass spectrometer. In addition, in order for the mass spectrometer to detect a chemical, it must first be ionized. Therefore, an ionization source must be used for most species and may or may not be effective for a specific chemical. These types of analytical instruments for non-targeted analyses are relatively expensive and technically complicated to operate. In addition, these instruments cannot detect all potential substances. However, non-targeted analyses can provide a higher degree of specificity in identifying individual chemical identifies that are capable of breaching a particular treatment barrier.
### Table 5.3  Application of the Surrogate/indicator Framework to an Overall Treatment Train (adapted from Drewes et al., 2008)

<table>
<thead>
<tr>
<th>Step</th>
<th>Surrogate Parameters</th>
<th>Indicator Compounds</th>
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<tbody>
<tr>
<td><strong>Validation Monitoring: Piloting or/and Commissioning</strong></td>
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<tr>
<td>1</td>
<td>Define and verify operational boundary conditions for each unit process comprising the overall treatment train after operating the system assuring steady-state conditions. Do operational boundary conditions meet design criteria within an acceptable range? If yes, proceed to step 2. If not, determine cause for deviation.</td>
<td><strong>Baseline Monitoring:</strong> Conduct occurrence study to confirm presence of viable indicator compounds in the influent of each <strong>unit operation</strong></td>
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<tr>
<td>2</td>
<td>Quantify surrogate, e.g., conductivity rejection of overall system. Is conductivity rejection within previously observed range and does it meet performance specification of manufacturer? If yes, proceed to step 3 If not, determine cause for deviation, for example by quantifying conductivity rejection of individual pressure vessels</td>
<td><strong>Baseline Monitoring:</strong> Identify 5-10 suitable indicator compounds for spiking study (challenge test) at pilot-scale</td>
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<td>3</td>
<td><strong>Validation Monitoring:</strong> Quantify removal differential of viable surrogate parameter ( \Delta X_i = (X_{i,in} - X_{i,out})/X_{i,in} )</td>
<td><strong>Validation Monitoring:</strong> Conduct spiking study with select indicator compounds (5-10) to determine the removal differentials under pre-determined operating conditions: ( \Delta Y_i = (Y_{i,in} - Y_{i,out})/Y_{i,in} )</td>
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<tr>
<td>4</td>
<td>Select viable surrogate and operational parameters for each unit process</td>
<td>Select 3-6 indicator compounds from categories classified as “Good removal”</td>
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<td><strong>Compliance Monitoring: Full-scale Operation</strong></td>
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<td>5</td>
<td>Confirm operational boundary conditions of full-scale train and removal differential ( \Delta X_i ) for selected surrogate and operational parameters</td>
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<tr>
<td>6</td>
<td><strong>Operational Monitoring:</strong> Monitor differential ( \Delta X_i ) of select surrogate and operational parameters for each unit process or/and the overall treatment train on a regular basis (daily, weekly)</td>
<td><strong>Verification Monitoring:</strong> Monitor differential ( \Delta Y_i ) of selected indicator compounds for each unit process or/and the overall treatment train regularly, but less frequently (semi-annually, annually).</td>
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5.4.2 Rapid In Vitro Bioassays

While chemical monitoring provides quantitative assessment of contaminants in a water sample, in vitro bioassay monitoring complements chemical analysis, particularly for exploring unknown compounds and mixture effects. These rapid bioassays provide a more comprehensive chemical evaluation of water and provide information as to the occurrence of classes of compounds based on relevant human toxicology endpoints. This is especially relevant for potable water reuse where composition can be highly unpredictable and infinitely variable. In addition, oxidation and biological processes often result in transformation products (including DBPs) which are largely unknown and uncharacterized (Krasner et. al., 2006; Richardson, 2007; Mitch et. al., 2008).

In vitro bioassays generally utilize mammalian cell lines, which are often derived from cancer cells which tend to grow robustly in laboratory settings. Some bioassays do rely on bacteria or fungi cells, such as the well-known Ames assay for mutagenicity (Leusch and Snyder, 2015). Water samples are usually extracted using solid-phase extraction and the resulting extracts dosed into cells (Jia et. al., 2015). It is difficult to simplify the vast diversity of available bioassays, which incorporate various and often overlapping modes of action, and at the same time remain scientifically accurate. One compromise suggested by Escher and Leusch (2011) is to sort bioassays in five broad categories based on a simplified cellular toxicity pathway: one group is a measure of metabolic response, three are based on the type of interaction with the target molecule (non-specific, specific and reactive toxicity), and the fifth is a measure of cellular defense mechanisms (adaptive stress response).

A recent study applied 103 bioassays for approximately 30 endpoints to various water samples, including reclaimed water. That study reported a significant response with treated sewage in most endpoints, but a gradual loss of activity in most assays during advanced treatment, with only a few assays picking up activity in the reclaimed water (Escher et. al., 2014). This is largely in agreement with other studies that have monitored many of these endpoints in recycled water previously (Leusch and Snyder, 2015). It is important to point out that at this stage of bioassay implementation, they are generally used as analytical tools that can sensitivity and effectively provide occurrence information for classes of chemicals. Responses from in vitro bioassays should not be interpreted directly to public health safety, or risk, from resulting cellular responses alone.

5.5 References

Drewes, J.E., et al., Development of Indicators and Surrogates for Chemical Contaminant Removal during Wastewater Treatment and Reclamation - Final Report. 2008, WateReuse Foundation: Alexandra, VA
CHAPTER 6.

Source Water Treatment Facility Risk Management

6.1 Introduction

What are Hazards, What are Risks? And, Why Bother

Before discussing risk analysis at any level, it is imperative to define certain key terminology. Therefore, within the context and framework of SWTF operation, the following working definitions for hazards are risks are considered:

- **Hazard**: An occurrence, event or situation with the potential for creating failure, damage, loss of function, deterioration of Supply Water Quality or consistency of delivery.
  - An example of a hazard is excessive ragging of a mixer in an anoxic tank.

- **Risk**: The probability (likelihood) of a specific outcome occurring within a specified time period. Risk is a complex function of probability, consequence and vulnerability.
  - For example – the risk of having a supply-water ammonia concentration greater than a specified level.

So, why should designers and operators of a SWTF pay attention to this?

The ultimate aim of the SWTF is to safeguard the delivery and reliability of the Supply Water provided to the AWT. This enables efficacious and sustainable operation of the AWPF. Arguably, the SWTF is the most effective barrier for a wide range of bulk, aggregate and emerging contaminants. Thus, a comprehensive hazard and risk assessment is a critical aspect of developing a robust and reliable DPR program.

It is important to note that risk and hazard assessment are not new within the arena of SWTF design and operation. Historically, the standard metrics for reliability of wastewater treatment plant systems and unit operations originate from the EPA’s publication entitled Design Criteria for Mechanical, Electrical, and Fluid System and Component Reliability (USEPA, 1974). However, the pathogen-related health risks associated with DPR motivate a higher degree of emphasis on assessment of potential process failures, limitations, constraints and instabilities to minimize the risks associated with DPR.

There are two key components to the overall risk analysis:

1. Identification and assessment of hazards and risks (discussed in this subsection), and
2. Development of a mitigation and management plan for process control and actions when undesirable events occur (discussed in the next subsection).

There are several different hazard and risk evaluation techniques applicable to SWTF risk assessment (Table 6.1 and 6.2). A utility should determine the most effective approach based on resource availability and risk analysis objective/scope.

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<table>
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<tr>
<th>Methodology</th>
<th>Comments/Notes</th>
<th>References and/or Example Applications</th>
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| Failure Modes and Effects Analysis             | - A “bottom up” approach originally developed by military (c.f., MIL-P-1629A)  
  - Used to:  
    o recognize (identify) the failure/risk  
    o evaluate the failure and potential effects  
    o identify actions which would reduce the probability of failure/risk and/or reduce criticality of the failure/risk on key effects  
  - Results are strongly dependent on the team/individual’s understanding and knowledge of the process/systems (i.e., need process/I&C/other SMEs involved)  
  - Commonly used for mechanical/electrical components risk analysis (in numerous fields) | WRRF 09-03 WRRF 13-03                                                              |
| Hazard Analysis and Critical Control Points    | - Originally developed for food and beverage industry. Gaining popularity in DPR evaluations  
  - Integrates a wide array of hazards/risks – physical, chemical, biological, mechanical  
  - Critical Control Points (CCPs) can be established to reduce, eliminate or prevent hazards/risks  
  - Has been previously implemented for reuse projects |                                                                                      |
| Hazard and Operability Study                   | - Structured analysis to ask and develop responses to guiding “what-if” questions  
  - Typically used to identify effects and impacts of deviation from the “norm”  
  - Results are strongly dependent on the team/individual’s understanding and knowledge of the process/systems (i.e., need process/I&C/other SMEs involved)  
  - Commonly used by water professionals for process, system and plant-wide analysis |                                                                                      |
| Event Tree Analysis                            | - Used to assess events resulting from a specific “Initiating Event”  
  - Consequences of events must be well understood – i.e., knowledge of the process/systems is important - need process/I&C/other SMEs involved  
  - Powerful technique which can be used to model a sequence of events based on operational failure and develop a response plan.  
  - Can be quantitative – frequency or probability of outcomes of specific events can be quantified (based on operational history and/or SME experience) |                                                                                      |
### Methodology | Comments/Notes | References and/or Example Applications
--- | --- | ---
Fault Tree Analysis | • “Top Down” approach developed by Bell Labs begins with identification of undesirable outcome of event and working *backwards* to identify contributory events or causes  
• Powerful root-cause-evaluation technique which can used to identify the set of events/failures which would result in the specific undesirable outcome  
• Process/systems/interactions must be well understood – i.e., knowledge of the process/systems is important - need process/I&C/other SMEs involved  
• Can be quantitative – frequency or probability of specific causation-events can be quantified (based on operational history and/or SME experience). However – human error or other “generic” causes can, as a result, dominate and significantly influence the results | Taheriyoun and Moradinejad, 2015
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Comment</th>
<th>FMEA</th>
<th>HACCP</th>
<th>HAZOP</th>
<th>ETA</th>
<th>FTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantitative or Qualitative</strong></td>
<td>Can the results be quantified (absolute or relative scale)?</td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Qualitative, Quantitative</td>
<td>Qualitative, Quantitative</td>
</tr>
<tr>
<td><strong>Inductive or Deductive</strong></td>
<td>Does the analysis look “forward” at the effects of a particular hazard/failure (i.e., inductive) or “backward” at the potential causes of a particular outcome (i.e., deductive)?</td>
<td>Inductive</td>
<td>Inductive</td>
<td>Inductive</td>
<td>Inductive</td>
<td>Deductive</td>
</tr>
<tr>
<td><strong>Broad or Specific Hazard Analysis</strong></td>
<td>Is the approach/method designed for analysis using a broad (e.g., multi process) or specific view (e.g., single unit process or operation)?</td>
<td>Specific</td>
<td>Specific</td>
<td>Specific</td>
<td>Very Specific (identifying specific outcomes)</td>
<td>Very Specific (based on specific event/outcome)</td>
</tr>
<tr>
<td><strong>Single or Multiple Failure Analysis</strong></td>
<td>Does the approach/method emphasize single hazards/failure in isolation or is it geared towards evaluation of multiple/coincident or combination of failures/hazards?</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Multiple</td>
<td>Multiple</td>
</tr>
</tbody>
</table>
6.2 Identification of Critical Control and Attention Points

The hazard/risk analysis forms a basis for the identification of Critical Control Points (CCPs) or Attention Points (APs) within the treatment process. A CCP is a unit operation or step in the process where operations staff can affect change (through an activity) to prevent, reduce or eliminate the risk of an adverse outcome, which may be specific to that process (Hallilwell et. al., 2014; Walker et. al., 2016). Previous WRRF research efforts have developed and outlined a specific process to identify whether a given process/unit operation is a CCP within the context of HACCP (Hallilwell et. al., 2014; Walker et. al., 2016). Note that other risk analysis approaches were not considered as part of these efforts.

6.3 Operational Decision Support Tool for Risk Management

A comprehensive hazard/risk analysis enables a SWTF to identify and evaluate risks in addition to tools and data at their disposal to address these risks. An important step to addressing these risks is to establish an Operational Decision Support Tool (or Plan) which outlines actionable items, action levels and the required action/activity to mitigate or address specific risks. Note that risk management approaches such as HACCP specifically include development of corrective actions in addition to procedures to document these actions.

6.3.1 Identification and Management of Critical Limit Parameters

Each CCP has one or more target criteria or Critical Limit Parameters (CLPs) which can be monitored to validate performance. Note that hazard/risk analyses techniques such as fault tree analysis (FTA) can be used to identify CLPs and the quantitatively link CCP failure or adverse performance to specific outcomes. An example of a decision support tool related to supply water quality control is shown in Table 6-3. The level of complexity and integration with automated actions (via SCADA, for example) is SWTF/staff dependent. It is recommended that SWTF integrate a training program for operators to implement these decision support tools.
### Table 6.3  Examples\(^1\) of a Decision Support Tool for Actions to be taken based on DPR Supply Water Quality Monitored using Online Measurement Tools

<table>
<thead>
<tr>
<th>Critical Limit Parameter</th>
<th>Level/Reading</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply Water Turbidity</strong></td>
<td>&lt; Alert Level</td>
<td>• Periodic Instrument Validation</td>
</tr>
</tbody>
</table>
| | = Alert Level | • Inspect sample tubing/instrument (verify NOT false positive)  
• Assess separation process operation (e.g., sludge fluff blanket level, etc.)  
• Evaluate operating conditions and make operational modifications if required & possible (e.g., is HLR > design HLR – bring more clarifiers online)  
• Inform shift supervisor, separation process SME, AWP lead operator and AWP process SME  
• Evaluate and confirm readiness for mitigation measures\(^3\) (e.g., coagulant/polymer addition to improve settling/filtration) |
| | > Alert Level | • Inspect sample tubing/instrument  
• Implement mitigation measures  
• Inform shift supervisor, process SME and plant manager/Chief operator |
| | = Max. Level | • Inspect sample tubing/instrument  
• STOP flow of supply water to AWP process |
<table>
<thead>
<tr>
<th>Critical Limit Parameter</th>
<th>Level/Reading</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Water Ammonia-N</td>
<td>&lt; Alert Level</td>
<td>• Periodic Instrument Validation</td>
</tr>
<tr>
<td></td>
<td>= Alert Level</td>
<td>• Inspect sample tubing/instrument (verify NOT false positive)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Assess biological process current and recent-historical (e.g., previous 6 hours) trends (NH_3-N, DO, MLSS, WAS, etc.). If trend analysis indicates system/mechanical/control failure – address through corrective action plan (previously developed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Inform shift supervisor, biological process SME, AWP lead operator and AWP process SME</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If ammonia measurements through AWP process are manual – inform AWP operators and/or lab staff to initiate more frequent sampling/analyses until advised to stop</td>
</tr>
<tr>
<td></td>
<td>&gt; Alert Level</td>
<td>• Inspect sample tubing/instrument</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Implement mitigation measures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Inform shift supervisor, process SME and plant manager/chief operator</td>
</tr>
<tr>
<td></td>
<td>= Max. Level</td>
<td>• Inspect sample tubing/instrument</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Assess impacts on AWP process and DPR water quality (AWP process configuration dependent) and implement</td>
</tr>
</tbody>
</table>

**Notes:**

1. Note that this Table is provided as an example only and is not intended to be exhaustive. The complete set of parameters relevant at a particular SWTF will depend on the overall process configuration and should be developed through a HACCP process managed by SWTF senior personnel and process SMEs.
2. The Alert Level and Max. Level for each process parameter will be predetermined, documented and shown on the SCADA screen (Manager adjustable only).
3. SWTF specific mitigation measures should be developed as part of the overall SWTF operations plan.
4. The frequency of sampling required should be established by the process SME and plant manager(s) as part of the plant operations/strategy.
6.4 References


Taheriyoun, M., Moradinejad, S., Reliability analysis of a wastewater treatment plant using fault tree analysis and Monte Carlo simulation, Environ Monit Asses 187 (4186), 2015

Conclusions

7.1 Drivers for Potable Reuse

As noted in Chapter 1, throughout the United States and internationally, water crises are increasingly discussed in the popular press and on-line. Water shortages, surging population growth, and the possible impact of climate change will challenge current concepts of water supply management. A paradigm shift to expand the use of traditional reclaimed water use to potable reuse is inevitable. Specific drivers for direct potable reuse (DPR) have been identified and include:

- Lack of suitable hydrogeology for groundwater storage or large reservoirs to meet indirect potable reuse (IPR) requirements,
- Changing climatic patterns that vary across geographic regions and challenge current water supply and storage planning concepts,
- High costs associated with tertiary recycling for irrigation and other non-potable applications,
- Lower energy costs for production than other water supply alternatives (i.e. sea water desalination), and
- Developments in advanced water purification (AWP) and monitoring technologies.

7.2 Objectives of the Guideline

The primary objectives of this project were to:

1) Evaluate upstream wastewater treatment impacts (e.g. biological treatment through N/dN-nitrification/denitrification and other means, chemical treatment, industrial source control) on DPR source water quality and DPR processes
2) Evaluate impacts of hydraulic control mechanisms (e.g. flow equalization and source water storage buffers) on influent water quality and flow variations that “stress” the DPR process

This Guideline has reviewed the relationship between variable influent water quality and the extent of source control strategies implemented in a community and demonstrated that they have a direct impact on the performance of an IPR/DPR treatment process train. The Literature Compendium and Case Studies provide a significant amount of detail on these subjects and many good examples of source control programs, design considerations related to AWP and SWTF, operational issues that impact IPR/DPR systems, etc.
### 7.3 Project Outcomes

This Guideline was designed to assist a wide range of utilities at all stages of implementing IPR or DPR programs. Some utilities may have no formal IPR program and only are thinking about DPR. Others may be evaluating an IPR program at the study, planning or implementation level or are in the final stages of planning for DPR. The case studies and the conclusions drawn from them as well as other material gleaned from the literature and other sources should allow an increasing number of communities to plan for and implement a safe IPR/DPR program.

Each chapter in this Guideline provided a variety of insights into how upstream wastewater from the collection system can impact not only the SWTF and its impacts on DPR source water but also downstream advanced treatment processes. Also examined was the impact of hydraulic control mechanisms on influent water quality and flow variations that may stress advanced treatment processes for DPR applications.

Chapter 1 introduced the concept of an IRRF which incorporates the SWTF with AWP and illustrates three types of DPR scenarios which are referenced throughout the document.

Chapter 2 reviewed the impact that the quality and flow variation of the DPR supply water can have on the design and operation of the AWP processes as well as mitigation and design considerations to maximize efficiency and performance. Two example DPR treatment trains were highlighted and for each treatment train, a table outlining the AWP process, the process function, key design factors and key DPR supply water constituents that impact the design and operation of the treatment trains were covered in detailed tables. The overall findings show poor source water quality and/or wide flow variations can have significant impact on the AWP process design and operations. Such impacts would translate to increased capital and O&M costs of the AWP process.

Chapter 3 examined source control from a variety of different perspectives. Source control is a critical element of any potable reuse program, regardless of whether it is IPR or DPR. Source control is a combination of managerial and operational barriers that are implemented as part of a multi-barrier approach to eliminate or control the discharge of pollutants to wastewater that may be difficult to treat, impact maintenance and operations, potentially impact public or environmental health, and/or may impair the final quality of the treated water intended for DPR (APAI, 2105; Tchobanoglous et al., 2015). The chapter addressed the differences between “pretreatment” programs and “source control” programs, the key elements of source control programs for DPR, understanding the effectiveness of source control, and how a source control program may or may not differ from a program implemented for an IPR project. It was pointed out that source control is in the eye of the beholder and that as a utility embarks on establishing their program the interrelationships and differences between conventional pretreatment programs and source control should be fully understood. A detailed table described the key program elements of a pretreatment program and the resources that can be utilized to develop each of those elements.

One of the key elements that differentiates a pretreatment program from source control is a shift in focus from meeting discharge limits (pretreatment programs) to becoming part of an integrated water supply program (source control.) A detailed table identified 13 program elements and thoroughly described the formation and structure of those elements.

Some examples of international source control programs are provided as a resource. The chapter identifies 13 key elements to consider in the development of source control programs and strategies for DPR. The discussion also provides examples of potential sources of select compounds that can impact the downstream APWFs.
Chapter 4 provided guidance related to the configuration, process design and operation of a SWTF compatible with AWP for potable reuse. SWTFs have been historically designed and operated to achieve a high-quality effluent suitable for environmental discharge. Such end-point targets are readily achieved with a wide range of secondary and tertiary treatment alternatives. However, integration of an AWPF in the scheme requires a paradigm shift in the operation of SWTFs because the treated effluent is the supply water for the AWPF. Several principal objectives for IRRFs expanding to integrate AWPFs were identified and discussed. Some of the principal objectives for IRRFs expanding to integrate AWPFs include:

- Production of a consistently high quality supply water suitable for further treatment in the AWPF.
- Ability to detect a poor-quality supply water and divert flow away from the AWP process.
- Produce steady consistent flow.
- The chapter also focused the provision of guidance related to the configuration, process design and operation of a SWTF compatible with AWPFs for potable reuse. The focus of the Guideline involved the following elements:
  1) Nitrogen Management
  2) Flow and Load Variation Management
  3) Management of CECs
  4) Sidestream Management

Chapter 5 focused on SWTF process monitoring, control and risk management. While Chapters 3 and 4 examined the impact of source water control and source water treatment strategies on the variability in quality and production of supply water, the objective of this chapter was to review strategies and options to monitor and control SWTFs. Such monitoring and control is designed to manage, minimize and mitigate the risks associated with SWTF process upsets and/or deviations which would have a detrimental impact on the supply water quality or production consistency.

Chapter 6 enumerated a variety of strategies to manage potential hazards and risks associated with the design, operation and maintenance of DPR facilities.

### 7.4 Future Directions and Research Opportunities

This research project has taken many paths over the course of its development. Thus, there are many avenues of additional investigation and research that might be explored to further refine strategies for source control.

- Separate collection systems for SWTFs versus current standards for collection systems for WWTPs
- Urine picked up from holding tanks by truck
- Greywater recycled in homes as appropriate
- Blackwater (and greywater when not recycled) to existing collection system
- Industrial wastewater treated in separate satellite plants which is then piped directly to SWTFs or recycled within the industry for non-potable uses
- Federal standards under the SDWA should recognize DPR
- Research on new sensors and monitoring technologies both in-plant and within the collection system
- Development of additional surrogate/indicators for DPR supply monitoring
• Research on in-home toilet technology (e.g. Gates Foundation Reinvent the Toilet Challenge) for alternative strategies to reduce blackwater to the WWTP
• Research on the feasibility, cost and benefit of collection system monitoring approaches
• Research on how technologies being developed in the United States may be transferred to other areas of the world (and vice versa), some of which lack the resources available to construct facilities as described in this Guideline
• Regulations on the use and development of new chemicals in personal care products which may enter the DPR source water supply
• Shift the design paradigm that would consider the combination of wastewater, AWP and water treatment plants into one integrated facility to produce potable source water
• Develop scalable strategies for DPR for smaller utilities that do not have the same level of resources and sophistication as larger utilities.
• Research and development of verifiable technologies (strategies) for pathogen removal in SWTFs with appropriate credit and the impacts of particular forms of treatment to enhance such removal.
• Barriers that must be broken to establish credibility for pipe to pipe DPR systems that view integration of SWTF, AWT, and WTP to produce DPR.
• Research on additional requirements for hospitals discharging to collection systems that provide source water to SWTF facilities
• Ongoing consideration of the development of new commercial and personal care products and how they may impact contaminants that enter the collection system and impact WRRF