PROJECT NO.
4960

An Enhanced Source Control Framework for Industrial Contaminants in Potable Reuse

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Prepared by:

Tyler Nading, Larry Schimmoller, Talia Assi, Erik Desormeaux
Jacobs

Andy Salveson, Amos Branch
Carollo Engineers, Inc

Eric Dickenson, Kyle Thompson
Southern Nevada Water Authority

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For more information, contact:
The Water Research Foundation

1199 North Fairfax Street, Suite 900
Alexandria, VA 22314-1445
P 571-384-2100

6666 West Quincy Avenue
Denver, Colorado 80235-3098
P 303-347-6100

www.waterrf.org
info@waterrf.org

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Research Team

Principal Investigator:
Tyler Nading, PE
Jacobs

Co-principal investigators:
Amos Branch, PhD
Carollo Engineers, Inc.

Andy Salveson, PE
Carollo Engineers Inc.

Eric Dickenson, PhD
Southern Nevada Water Authority

Larry Schimmoller, PE
Jacobs

Project Team:
Ashley Waldron, PE
Jacobs

Brynne Weeks, PE
Carollo Engineers, Inc.

Erik Desormeaux, PE
Jacobs

Kyle Thompson, PhD, PE
Southern Nevada Water Authority (former)
Carollo Engineers, Inc. (current)

Talia Assi, PE
Jacobs

WRF Project Advisory Committee

Chris Wilson, PhD, PE
Hampton Roads Sanitation District

Erica Kalve
California State Water Resources Control Board

Peter Fox, PhD
Arizona State University

Talle Lopez
California Water Service

Tricia Lee
California State Water Resources Control Board

WRF Project Subcommittee or Other Contributors

Brian Bernados, PE
California State Water Resources Control Board

James Crook, PhD, PE, BCEE
Environmental Engineering Consultant

Jean Debroux, PhD
Kennedy Jenks Consultants

Al Garcia
United States Environmental Protection Agency

Jörg Drewes, PhD
Technical University of Munich

Adam Olivieri, Dr. PH, PE
EOA, Inc.

Brian Pecson, PhD, PE
Trussell Technologies, Inc.

Aleks Pisarenko, PhD
Trussell Technologies, Inc.

Megan H. Plumlee, PhD, PE
Orange County Water District

Rodrigo Tackaert, PE
Trussell Technologies, Inc.

George Tchobanoglous, PhD
University of California, Davis

Stephen Timko, PhD
Kennedy Jenks Consultants

Shane Trussell, PhD, PE, BCEE
Trussell Technologies, Inc.

Water Research Foundation Staff

John Albert, MPA
Chief Research Officer

Ashwin Dhanasekar
Research Program Manager

Participating Utilities

Case Study and Survey Participants:
City of Morro Bay, California
City of Pismo Beach, California
City of Santa Cruz, California
City of Altamonte Springs, Florida
Hampton Roads Sanitation District, Virginia
Los Angeles County Sanitation Districts, California
City of Palo Alto, California

Survey Participants:
Alexandria Renew Enterprises
Anne Arundel County Bureau of Utility Operations
Athens-Clarke County Public Utilities Department
City of Atlanta
City of Duncan
City of Farmington
City of Fayetteville
City of Hood River
City of Omaha
City of Orlando
City of Phoenix
City of Rio Rancho
City of Roseville
City of San Mateo
City of Stephenville
City of Tampa
City of The Dalles
City of Traverse City
City of Twin Falls
City of Walla Walla
City of Waynesboro
City of West Chicago
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Clark County Water Reclamation District
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Clean Water Services
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DC Water and Sewer Authority
Dublin San Ramon Services District
East Baton Rouge Sewerage Commission

East Bay Municipal Utility District
Gwinnett County Department of Water Resources
Houston Water
Jacksonville Electric Authority
King County – Wastewater Treatment Division
Las Virgenes Municipal Water District
Lincoln Transportation and Utilities
Los Angeles Sanitation and Environment
Loudoun Water
Madison Metropolitan Sewerage District
Massachusetts Water Resources Authority
Metro Wastewater Reclamation District
Metropolitan Government of Nashville and Davidson County
Metropolitan Sewer District of Greater Cincinnati
Metropolitan Water Reclamation District of Greater Chicago
NEW Water (brand of Green Bay Metropolitan Sewerage District)
Northeast Ohio Regional Sewer District
Orange County Sanitation District
Pima County Regional Wastewater Management
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Rio Rancho Utilities Department
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Salt Lake City Department of Public Utilities
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South Huron Valley Utility Authority
South Orange County Wastewater Authority
Spokane County Utilities
SUEZ
Town of Westerly
Trinity River Authority of Texas
Ventura Water
Village of Carol Stream
Water Corporation of Western Australia

Abstract and Benefits

Abstract:
Source control is a key element of potable reuse programs and one that has not been widely researched and documented. Enhanced Source Control Programs (ESCPs) have been implemented for potable reuse programs with varying approaches and objectives as each program must be designed to address the source water and collection system specific to each utility. This project researched common challenges across ESCPs and identified industrial contaminants that present the largest hazard to potable reuse. A state-of-knowledge review examined 262 industrial contaminants and categorized the contaminants by chemical properties, toxicity, removal by various advanced treatment processes, and types of industrial sources. A screening process was developed to identify the contaminants with the highest priority for monitoring or research for each of three conceptual advanced treatment trains. The project also included a broad survey with 80 utility respondents on common aspects of pretreatment programs and specific contaminants and industries that cause challenges. Detailed case study interviews were conducted with seven utilities to learn more about their pretreatment programs and ESCPs, providing a detailed understanding of how utilities view source control for potable reuse. The project culminated in a recommended step-by-step framework for utilities to implement Industrial ESCPs.

In total, this research helps future utilities understand how to design and implement an ESCP and summarizes best practices across the industry.

Benefits:

- This research identified industrial contaminants that should be monitored in potable reuse projects based on their toxicity and expected removal through advanced treatment processes.
- A database was compiled of anticipated removal by common treatment processes for each identified contaminant, as well as toxicological information and potential sources.
- The framework developed in this project provides a 13-step approach to developing an Industrial ESCP that can be followed by other utilities.
- The case studies summarized best practices, and in some cases very different approaches, across different utilities and provide estimates for the incremental costs for going from a pretreatment program to an ESCP.
- Water Research Foundation subscribers can access two web-based appendices to customize the research to a specific system.
- This framework developed from this project provides a systematic approach to implementing ESCPs.

Keywords: Enhanced Source Control Program, Pretreatment Program, Potable Reuse, Advanced Treatment, Industrial Contaminants

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Acronyms and Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
<	less than
>	greater than
≥	greater than or equal to
ADC	Adult Dose Correlation
AFFF	aqueous film-forming foam
APC	Advanced Purification Center
ASRWRF	Altamonte Springs Regional Water Reclamation Facility
AWT	advanced water treatment
AWTP	advanced water treatment plant
BAC	biological activated carbon
BGD	billion gallons per day
BMP	best management practice
BNR	biological nutrient removal
BOD	biochemical oxygen demand
CA	California
CAS	conventional activated sludge
CCL	Contaminant Candidate List
CEC	contaminant of emerging concern
CFR	code of federal regulations
CIU	categorical industrial user
COD	chemical oxygen demand
CSF	cancer slope factor
CWT	centralized waste treatment
DBP	disinfection byproduct
DOC	dissolved organic carbon
DPR	direct potable reuse
DWG	Drinking Water Guidelines
DWTP	drinking water treatment plant
EC	electrical conductivity
ERG	enforcement response guide
ERP	Enforcement Response Plan
ESCP	enhanced source control program
F	food service/processing
F.A.C.	Florida Administrative Code
FOG	fats, oils, and grease

FTE	full-time equivalent
G	general permits
g/mol	gram(s) per mole
GAC	granular activated carbon
gpd	gallon(s) per day
HA	health advisories
HAL	Health Advisory Levels
HRSD	Hampton Roads Sanitation District
ICM	iodinated contrast media
ICRQ	Industrial Contaminant Risk Quotient
ICSS	Industrial Contaminant Screening Score
IPR	indirect potable reuse
IRIS	Integrated Risk Information System
IU	industrial user
IW	industrial waste
IWS	industrial waste survey
JEA	Jacksonville Energy Authority
JRTP	James River Treatment Plant
JWPCP	Joint Water Pollution Control Plant
kg/mg	kilogram(s) per milligram
LACSD	Los Angeles County Sanitation Districts
MBBR	moving bed bioreactor
MBR	membrane bioreactor
MCL	Maximum Contaminant Level
MF	microfiltration
mg/kg/day	milligram(s) per kilogram per day
mg/L	milligram(s) per liter
mgd	million gallon(s) per day
mJ/cm2	millijoule per square centimeter
MWRA	Massachusetts Water Resources Authority
n/a	not applicable
NDMA	n-nitrosodimethylamine
ng/L	nanogram(s) per liter
NL	Notification Level
NMOR	nitrosomorpholine
NPDES	National Pollutant Discharge Elimination System
NPP	National Pretreatment Program
NSCIU	non-significant categorical industrial user
NTP	Nansemond Treatment Plant

O&M	operation and maintenance
OCPSF	organic chemicals, plastics, and synthetic fibers
OCSD	Orange County Sanitation District
OP	orthophosphate
PAS	Potomac Aquifer System
PFAA	perfluoroalkyl acid
PFAS	per- and polyfluorinated substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFDA	perfluorodecanoic acid
PFHpA	perfluoroheptanoic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonate
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PFPeA	perfluoropentanoic acid
POC	pollutant of concern
POTW	publicly owned treatment works
PSES	pretreatment standards for existing sources
PSNS	pretreatment standards for new sources
QMRA	quantitative microbiological risk assessment
QSAR	quantitative structure-activity relationship
RfD	reference dose
RO	reverse osmosis
RSC	Relative Source Contribution
RSD	risk-specific dose
RV	recreational vehicle
RWQCP	Regional Water Quality Control Plant
SBR	sequencing batch reactors
SCWD	Soquel Creek Water District
SIU	significant industrial user
SOP	standard operating procedures
SRC	Sustainable Water Initiative for Tomorrow (SWIFT) Research Center
SUO	Sewer Use Ordinance
SWRCB	State Water Resources Control Board in California
SWIFT	Sustainable Water Initiative For Tomorrow
TCEP	tris(2-chloroethyl) phosphate
TDCPP	tris(1,3-dichloro-2-propyl) phosphate

TDS	total dissolved solids
TMF	Technical, Managerial, and Financial
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorous
TSS	total suspended solids
TTO	Total Toxic Organics
TWDB	Texas Water Development Board
UCMR	Unregulated Contaminant Monitoring Rule
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet
UV/H2O2	ultraviolet hydrogen peroxide advanced oxidation
UVAOP	ultraviolet advanced oxidation process
VOC	volatile organic chemical
WRF	The Water Research Foundation
WRP	water reclamation plant
WTP	water treatment plant
WW	wastewater
WWTP	wastewater treatment plant
ε	absorption coefficient
ϕ	quantum yield

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Executive Summary

The potable reuse community has made great strides towards understanding advanced treatment technology and the removal of pathogens and chemical contaminants. Source control is comparably important to advanced treatment in the protection of public health for potable reuse but has been much less documented and researched. In particular, additional research is needed on the risk posed by both regular and intermittent discharges of industrial contaminants and the ability of advanced treatment systems to remove these contaminants.

Potable reuse systems treating wastewater effluent are often referred to as advanced water treatment plants (AWTPs) because they provide multiple barriers of treatment for pathogens and chemical contaminants and implement advanced treatment technologies. Pathogen removal has been well documented and potable reuse projects are designed with robust treatment trains that provide human health protection against the acute risk posed by pathogens during a community outbreak or nonstandard operation. Similarly, much research has been done on the occurrence and removal of chemical contaminants in advanced treatment and AWTPs have been designed and operated to achieve a high degree of removal. However, without source control, it is plausible that an influent chemical spike could cause a chemical that is normally removed to temporarily occur above its guideline or regulation as most AWTPs are not specifically designed to treat excursion-level concentrations for chemical contaminants.

Furthermore, establishing meaningful regulations to limit discharges from industries is inherently difficult because the vast amount of chemicals that are discharged do not have well-studied toxicological impacts. Changes in industrial processes occur frequently and result in the introduction of new contaminants, leaving regulations to lag behind. As such, there is a need to continuously assess and understand the types of contaminants that are used by different industry types and their impact on potable reuse.

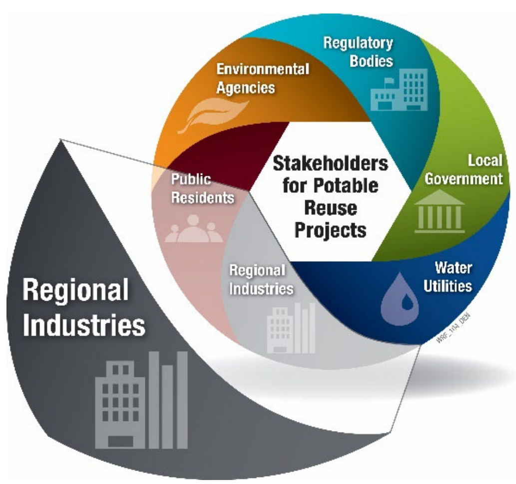

Figure ES-1. Potable Reuse Stakeholders.

This project focuses on identifying the risk of industrial contaminants to potable reuse systems and provides recommended mitigation strategies for utilities. These recommendations are summarized in an industrial enhanced source control program (ESCP) framework that identifies the steps needed to develop and implement an Industrial ESCP. The research highlights that local industries are stakeholders for potable reuse systems because they are integral to the regional water system, as illustrated on Figure ES-1. Including industries within ESCP planning helps them understand that they are stewards of the local water system and will be educated on the risks they pose to the potable reuse system, which can lead to improved discharge practices. It is noted throughout this report, however, that the Industrial ESCP is just one component of an overall ESCP that is needed for all potable reuse projects and includes considerations for residential and commercial dischargers.

ES.1 Project Approach

The goal of this project was to identify industrial contaminants that can impact potable reuse treatment and provide recommended mitigation strategies. The overall project objectives were as follows:

- Identify contaminants or families of contaminants related to industry or manufacturing and review the types of industries that may use or discharge these contaminants.
- Group listed contaminants in terms of risk to water quality and impact to advanced treatment.
- Develop mitigation strategies, including treatment, inspection, and monitoring.

This project was broken down into four tasks to achieve the project objectives, as depicted on Figure ES-2 and described in the following paragraphs. This executive summary, and the overall report, is organized sequentially according to the four tasks. The tasks culminate in the development of an overall framework for developing Industrial ESCPs.

- Task 1: Conduct a state-of-knowledge review of industrial contaminants that impact potable reuse operation, the hazard to public health, and the types of industries that discharge these contaminants.
- Task 2: Survey a wide range of wastewater treatment plants (WWTPs) to understand the prevalence of different industries, common challenge contaminants, and features of existing pretreatment programs.
- Task 3: Perform detailed case study evaluations of existing pretreatment programs and ESCPs that are either currently in operation or will be in the near future to identify best practices, risks of specific industries, and potential gaps.
- Task 4: Develop a step-by-step framework for utilities to develop an Industrial ESCP based on best practices and mitigation strategies determined in Tasks 1 through 3.

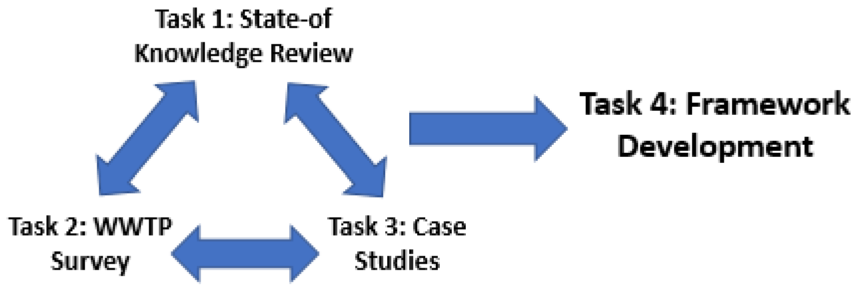

Figure ES-2. Task Flow Chart.

ES.2 Enhanced Source Control Programs

Successful potable reuse systems require effective pretreatment and source control programs that address residential, commercial, and industrial flows entering the wastewater collection system. Industrial dischargers can pose significant risk due to the types of contaminants used in industrial processes, the potential for variability in discharge quality, and the higher point source flows relative to residential and commercial users. The goal of source control programs is to keep difficult-to-treat or otherwise problematic contaminants from entering the collection system.

Establishing definitions for industrial pretreatment, conventional source control programs, and ESCPs is important to understanding this report. This project focuses on ESCPs, and specifically on industrial-focused ESCPs, and provides recommendations for utilities to enhance existing pretreatment programs to meet the potable reuse program needs. The term ESCP is currently used within the industry to designate a program that is focused on potable reuse. The report is mostly focused on ESCPs but also discusses elements of existing pretreatment programs.

This report focuses specifically on mitigating the risk of industrial contaminants to potable reuse systems. A full ESCP should also include residential and commercial impacts on the potable reuse system. As those sources are not discussed in this report, the project team has deliberately used the term "Industrial ESCP" throughout this report. This was done to acknowledge that there are more steps needed to create a holistic ESCP. Ideally, a utility will follow the steps in this report to create an Industrial ESCP and incorporate it into the overall ESCP after going through similarly detailed steps to evaluate and mitigate the risk of residential and commercial contaminants. Additional research projects discuss best practices for residential and commercial dischargers into potable reuse systems which often focus on outreach and education rather than sampling and enforcement.

What is Enhanced Source Control?

Pretreatment Program: Activities associated directly with the National Pretreatment Program requirements (40 CFR § 403). The focus is on industrial monitoring and pretreatment.
Source Control Program: Activities under a Pretreatment Program associated with limiting the discharge of contaminants into a wastewater collection system that can impact wastewater treatment, worker health and safety, or resource recovery.
Enhanced Source Control Program: Enhancements to a source control program that are enacted specifically for potable reuse and public health protection.
Industrial Enhanced Source Control Program: A component of an ESCP that focuses exclusively on industrial dischargers.

ESCPs should account for the risk of discharged contaminants to a particular potable reuse system and are not "one size fits all" programs. A robust ESCP requires an understanding of the contributors to the collection system, the risk posed by each, and the most appropriate mitigation strategies.

Relevant objectives of the National Pretreatment Program (NPP) are shown on Figure ES-3, as derived from *Code of Federal Regulations* Title 40 Part 403. When potable reuse systems are employed, ESCPs enhance the focus from just WWTP performance to include AWTP performance and from focusing on protecting the health of the receiving water to also protecting public health. It should be noted that the NPP has additional objectives outside of just preventing pollutants that are pass-through and interference risks. The NPP also focuses on protecting the quality of other beneficial uses of the publicly owned treatment works (POTW), such as biosolids application, worker health and safety, and other locally specific uses.

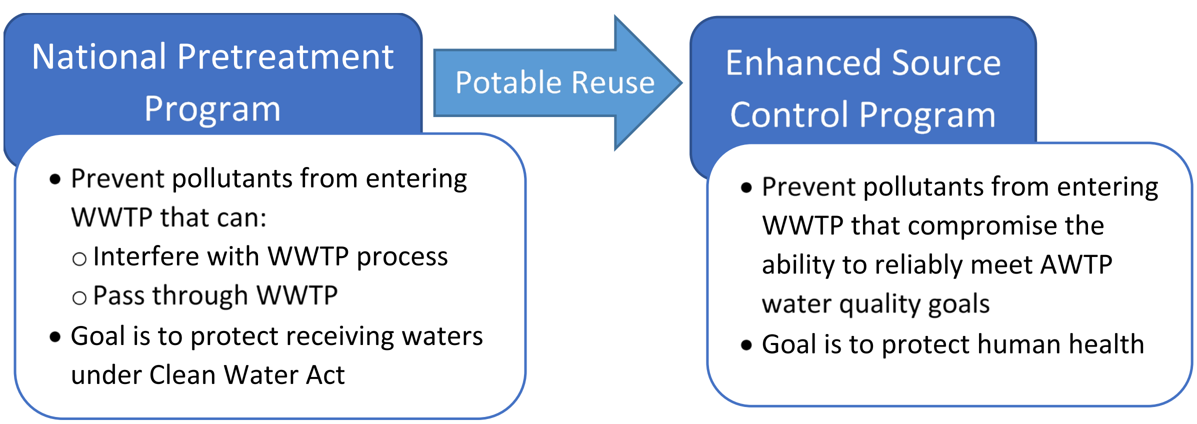

Figure ES-3. Objectives of National Pretreatment and Enhanced Source Control Programs.

The NPP has proven effective at limiting the introduction of non-domestic pollutants into WWTP systems (Tchobanoglous et al. 2015) and provides an existing structure for ESCPs. Where already implemented, the NPP provides an excellent basis for development of an ESCP; for larger utilities with robust NPPs, the progression to an ESCP may not require significant cost or resources. However, for smaller utilities with a voluntary or no pretreatment program that is not regulated by the NPP, implementation of an ESCP will require new staff and significant resources.

At its core, an ESCP consists of additional monitoring for contaminants relevant for potable reuse, a risk assessment of potential contaminants of concern, a pollutant tracking strategy, and mitigation strategies for the identified contaminants of concern; this is true for the Industrial ESCP and the overall ESCP. The goal is not to completely overhaul the existing pretreatment program or to significantly increase the local limits program, but rather to supplement the existing pretreatment program. In fact, some ESCPs can be limited with minimal or no new limits for permitted industries, as described in the case studies in Chapter 4. Rather, the ESCP is the acknowledgment of a new class of contaminants that must be monitored and whose sources must be identified and quantified. This report illustrates how important it is for all potable reuse systems to have ESCPs and provides a framework to help utilities in implementation, whether it is building from an existing NPP or creating a new program altogether.

ES.3 Project Scope

Identifying all contaminants that are a risk to any potable reuse system is too broad of a task for a single project. The following scope clarifications were identified to provide a boundary for this research:

- This project focuses on industrial contaminants and thus develops an Industrial ESCP. It is acknowledged that a robust ESCP will also include considerations for residential and commercial dischargers and it is recommended that the Industrial ESCP be incorporated into the larger ESCP.
- The recommendations for Industrial ESCPs are primarily directed toward significant industrial users (SIUs) as defined by the NPP. Other terms, such as permitted industries or industrial users, are not strictly defined and can have different operational meanings for different utilities.
- This project does not distinguish between direct potable reuse (DPR) and indirect potable reuse. The goal was to create a framework that is relevant for all potable reuse projects and can be adapted based on project needs.
- Industrial contaminants for the state-of-knowledge review were identified based on established regulations and guidance. Toxicological information and removal across advanced treatment processes was based on existing published and unpublished research. No new removal studies or toxicological evaluations were performed as part of this project. It is acknowledged that this review represents a small percentage of the total number of industrial contaminants that are currently in production; as such, it is recommended that this list be continuously reviewed as more information on industrial contaminants becomes available.
- The state-of-knowledge review focused on industrial contaminants with the potential for interference or pass through at the AWTP. With few exceptions, water treatment chemicals, disinfection byproduct precursors (DBPs), chemicals banned in the USA, and chemicals with biological origin were not included.

ES.4 Task 1: State-of-Knowledge Review

A state-of-knowledge review was conducted for industrial contaminants that impact potable reuse operation, their hazard to public health, and the types of industries that discharge the contaminants. A total of 262 industrial contaminants were short-listed, assessed, and ranked based on the potential hazard to typical AWTP systems. This review included the following activities:

1. Identifying industrial contaminants relevant to potable reuse and reviewing technical reports and peer-reviewed papers for data on the removal of industrial contaminants in wastewater and advanced treated water, toxicological information, and chemical properties.
2. Selecting representative advanced treatment processes and typical treatment trains and estimating the treatment effectiveness against industrial contaminants.
3. Screening and organizing contaminants based on potential to interfere with or pass through AWTPs.
4. Defining and calculating an Industrial Contaminant Screening Score (ICSS) for each contaminant based on toxicity and AWTP removal.
5. Recommending areas for additional research based on knowledge gaps identified in this review.

ES.4.1 Contaminant Identification and Sorting

Several sources were selected to help identify contaminants that have a known toxicological impact, are still in use or distribution, and have industrial sources. Table ES-1 lists the different regulations, guidelines, and groupings that were reviewed. The majority of the sources are lists of regulations, guidelines, or goals that have been established based on health risks. Pharmaceuticals that have aquatic ecosystem risk quotients greater than one (Oliveira et al. 2015) were included. Pesticides were included if they were one of the top 25 pesticides used in agriculture in the United States in 2012 (Atwood and Paisley-Jones 2017).

Table ES-1. Lists of Contaminants Used for Candidates for Inclusion in the Review.

USEPA Primary MCLs	USEPA Secondary MCLs	USEPA Health Advisory Levels
USEPA CCL / UCMR	CA Notification Levels	CA Toxics Rule
PFAS	Major pharmaceuticals	Australian Reuse Guidelines
WRF 4494 Health-Based Indicators	Top 25 Pesticides	World Health Organization Drinking Water Goals
Australian Drinking Water Goals	Canadian Drinking Water Goals	United Kingdom Drinking Water Goals

Notes: CA = California; CCL = Contaminant Candidate List; MCL = Maximum Contaminant Level; PFAS = per- and polyfluoroalkyl substances; UCMR = Unregulated Contaminant Monitoring Rule; USEPA = U.S. Environmental Protection Agency; WRF = Water Research Foundation

Once the complete list of contaminants was created, there was a significant amount of research needed to omit contaminants not relevant, such as those no longer permitted in the United States (e.g., banned pesticides) and contaminants not related to industrial discharges, such as pathogens, biotoxins, disinfection byproducts (except *N*-nitrosodimethylamine [NDMA]), water treatment chemicals, and combustion byproducts. The result was 262 industrial contaminants that the project team recommends considering at the beginning of a potable reuse project. These contaminants are shown in Appendix A and discussed in detail in Chapter 2. It is worth noting that of the 126 EPA priority pollutants, 74 were included in this evaluation.

ES.4.2 Treatment Trains and Pass-Through Hazard Assessment

The next step was to define typical potable reuse treatment trains and review the treatment effectiveness of each train against the 262 identified industrial contaminants. Figure ES-4 shows the three trains selected.

- Train A is a membrane-based reuse train consisting of microfiltration/ultrafiltration, reverse osmosis (RO), and ultraviolet hydrogen peroxide advanced oxidation (assumed ultraviolet [UV] dose of 1,000 millijoules per square centimeter [mJ/cm^2]).
  Microfiltration/ultrafiltration is not shown in Figure ES-4 as it was not considered a robust barrier to industrial contaminants.
- Train B is a carbon-based (non-RO) reuse train consisting of ozonation, biofiltration, granular activated carbon (GAC) adsorption, and UV disinfection (assumed UV dose of 276 mJ/cm^2).
- Train C is the membrane-based reuse train (Train A) after ozonation and biological activated carbon. Train C, or a variation of it, would be the required system to meet draft criteria for DPR in California (CWB 2021a).

Each treatment train included the upstream WWTP and a downstream conventional water treatment plant in addition to the advanced treatment train. Utilities considering other combinations of the same processes could estimate the overall removal using the information provided in Appendix A.

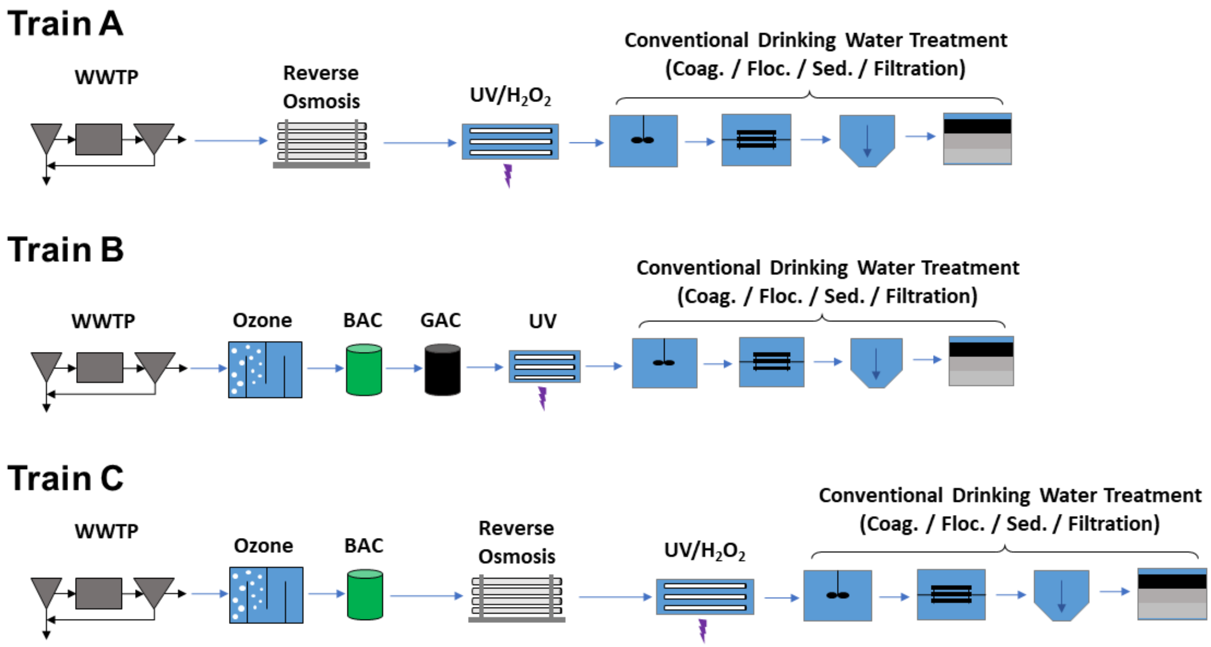

Figure ES-4. Reuse Treatment Trains Assessed.

ES.4.3 Pass-Through and Interference

Each of the 262 contaminants identified were reviewed against the three treatment trains and categorized as pass-through hazard, interference hazard, both, or neither. A pass-through hazard is defined as a contaminant that has less than 90 percent (%) removal across an advanced treatment train. The removal of all 262 contaminants across each of the selected advanced treatment processes was evaluated based on available literature and chemical properties. Semiquantitative removal categories were identified to characterize estimated removal: Excellent (greater than or equal to 90%), Good (60 to 89%), Fair (20 to 59%), Poor (0 to 19%), and Negative (less than 0%). The midpoint of the removal category was used to calculate the overall percent removal across the three treatment trains. This procedure resulted in conservative screening scores for certain contaminants as contaminants with 99% removal in literature were placed in the Excellent category and thus 95% (the midpoint) was used in the overall treatment train calculation. The conservative approach was considered appropriate to achieve the goal of a high-level screening. A high priority of certain contaminants does not constitute an unacceptable global risk, rather, it suggests that further site and process specific analysis could be warranted.

An interference hazard is defined as a contaminant that can inhibit or disrupt the treatment system's processes or operations and compromise the safety of the water by means other than pass-through. Many interference hazards were identified for each treatment train, though it is acknowledged that upstream or downstream treatment should be designed to mitigate the impacts of most of the interference hazards. Examples of interference hazards include oxidant and radical scavenging, membrane scaling, biological inhibition, and contaminants with the potential to biodegrade or oxidize into other chemicals that would be more toxic.

Table ES-2 provides the list of pass-through and interference hazards for each of the AWTP trains selected. Section 2.7 of this report provides detail on the selection of each hazard and the type of interference hazard that it presents.

Table ES-2. Interference and Pass-Through Hazards for Trains A, B, and C.

Contaminant	Train A Interference	Train A Pass-Through	Train B Interference	Train B Pass-Through	Train C Interference	Train C Pass-Through
1,4-Dioxane		✓		✓		
2,4,6-Trichlorophenol	✓		✓		✓	
8:2 Fluorotelomer Unsaturated Carboxylic acid (8:2 FTUCA)	✓		✓		✓	
Acetone	✓		✓		✓	
Alachlor			✓			
Aluminum				✓		
Ammonia	✓		✓		✓	
Aniline			✓			
Atrazine	✓		✓		✓	
Barium	✓			✓	✓	
Bromide			✓		✓	
Cadmium				✓		
Calcium	✓			✓	✓	
Chloride				✓		
Chromium	✓		✓	✓	✓	
Clarithromycin	✓		✓		✓	
Cobalt				✓		
Copper				✓		
Diatrizoic Acid	✓		✓	✓	✓	
Erythromycin	✓		✓		✓	
Fluoride				✓		
Gabapentin				✓		
Iodide	✓		✓		✓	
Iohexol			✓			
Iomeprol			✓			
Iopamidol			✓			
Iopromide			✓			
Iron	✓				✓	
Isopropyl Alcohol	✓		✓		✓	
Mancozeb			✓		✓	
Mercury				✓		
Metam	✓		✓		✓	
Methadone	✓		✓		✓	
Metolachlor			✓			
Nickel				✓		
Nitrate		✓		✓		✓
Nitrite			✓		✓	
NDMA		✓		✓		
NMOR				✓		
PFBS				✓		

(Continued)

Table ES-2. Continued.

Contaminant	Train A Interference	Train A Pass-Through	Train B Interference	Train B Pass-Through	Train C Interference	Train C Pass-Through
PFBA				✓		
PFDA				✓		
PFHpA				✓		
PFHxS				✓		
PFHxA				✓		
PFNA				✓		
PFOA				✓		
PFOS				✓		
PFPeA				✓		
Silver			✓		✓	
Strontium				✓		
Sulfamethoxazole	✓		✓		✓	
Sulfate				✓		
Sulfide	✓		✓		✓	
Tin	✓		✓		✓	
Uranium	✓		✓	✓	✓	
Zinc				✓		

ES.4.4 ICSS Screening

After contaminants were reviewed for pass-through and interference potential, they were again screened to develop an ICSS. The ICSS accounts for toxicity and removal for each contaminant across the three advanced treatment trains. Note that ICSS is not a metric of risk because it does not incorporate concentration or exposure. Rather, it is a tool to prioritize contaminants for collecting occurrence data. This was done so that contaminants with higher toxicities or less removal would be prioritized for monitoring over those with lower toxicities or higher removal. Chapter 5 discusses how to incorporate the ICSS into a risk assessment once the site-specific occurrence data for prioritized contaminants are known.

ICSS was calculated by dividing the estimated fraction of the contaminant remaining after advanced treatment (1 – $R_{overall}$) by the lower of two toxicity metrics: oral chronic reference dose (milligrams per kilogram per day [mg/kg/day]) or risk-specific dose (mg/kg/day). This provides a metric that prioritizes the contaminants based on pass-through potential and toxicity. Though, it is acknowledged that many of the percent removal estimations are conservatively low based on the semiquantitative approach used in the review. It is recommended that ICSS values be updated with site-specific removal values, as available. The ICSS calculation is shown in Equation ES-1.

$$ICSS = (1 - R_{overall})/\min\{RfD, RSD\} \qquad \textbf{Equation ES-1}$$

The highest 20 ICSS contaminants for each train are shown in Table ES-3. A higher ICSS means that the contaminant has a higher potential to be a challenge for the potable reuse train. However, the site-specific sampling data is needed to identify the risk of each contaminant, as discussed in Section 5.2. ICSS scores for all contaminants evaluated can be found in Appendix A.

The ICSS values ranked for each train indicates the following:

- NDMA has the highest ICSS for all three trains, indicating it should always be monitored in potable reuse projects.
- Perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), and nitrosomorpholine (NMOR) are present in the top four for each train. This was not expected due to the high rejection of each chemical for Trains A and C but is driven by the high toxicity of each contaminant.
- In general, Train B has higher ICSS values due to the Excellent removal of many contaminants by RO in Trains A and C.

Table ES-3. Top 20 ICSS Contaminants for the Three Treatment Trains.

No.	Train A		Train B		Train C	
	Contaminant	ICSS	Contaminant	ICSS	Contaminant	ICSS
1	NDMA	76500	NDMA	76500	NDMA	45900
2	PFOA	2500	PFOA	27500	PFOA	2500
3	PFOS	1500	NMOR	10050	PFOS	1500
4	NMOR	503	PFOS	7500	NMOR	503
5	1,4-Dioxane	113	Cobalt	2000	Cobalt	100
6	Cobalt	100	PFBS	2000	PFBS	100
7	PFBS	100	PFBA	700	Uranium	77
8	Uranium	77	Mercury	675	PFBA	35
9	PFBA	35	Arsenic	600	Mercury	34
10	Mercury	34	Chromium	600	Arsenic	30
11	Arsenic	30	Uranium	385	Chromium	30
12	Chromium	30	Cadmium	300	1,4-Dioxane	17
13	Cyanide	27	1,4-Dioxane	150	Cadmium	15
14	2,4,6-Trichlorophenol	25	Nickel	30	TCEP	10
15	1,2,4-Trichlorobenzene	18	TCEP	10	TDCPP	2.5
16	Atrazine	17	Selenium	7.0	Nickel	1.5
17	Cadmium	15	Fluoride	5.1	Atrazine	0.86
18	TCEP	10	Iodide	5.0	Carbon Tetrachloride	0.63
19	1,2-Dichloroethane	8.0	Copper	3.8	Selenium	0.35
20	TDCPP	2.5	Carbon Tetrachloride	3.1	Fluoride	0.25

ES.4.5 Research Gaps

This review also determined that there are significant research data gaps, especially in the expected removal of some of the industrial contaminants by different treatment processes. For example, as illustrated on Figure ES-5, the most under-studied processes for industrial contaminants from a water reuse context were (1) biofiltration, (2) WWTPs, and (3) UV photolysis. More research on the effectiveness of different treatment processes for these industrial contaminants will help provide updated lists of hazard potential. An additional research gap is the availability of toxicity data. Only 169 out of the 262 contaminants evaluated had reliable toxicity data, limiting the ability to calculate ICSS values.

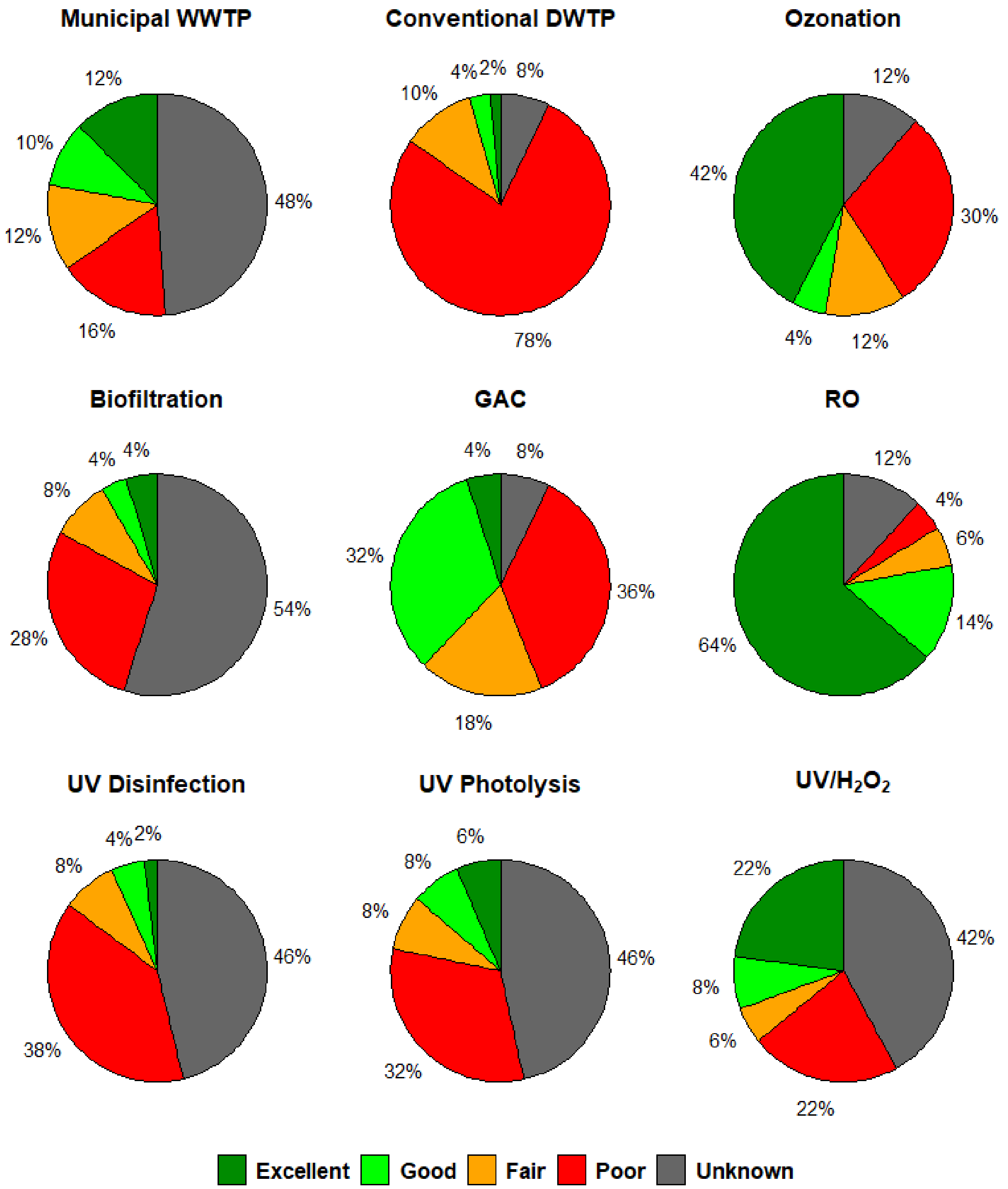

Figure ES-5. Pie Charts of Semiquantitative Removal Categories of 262 Reviewed Contaminants within Each of Nine Reviewed Treatment Processes.

ES.5 Task 2: Wastewater Treatment Plant Survey

The next task was to survey a wide range of utilities on pretreatment programs and ESCPs. A survey was developed and sent to 93 utilities and responses were received from 80 utilities (shown in Figure ES-6), which operated 355 different WWTPs. Combined, these utilities serve 58.5 million customers (approximately 20% of the United States population) and provide 7.9 million service connections. The treatment capacity for each participating utility varied from as little as 0.25 million gallons per day (mgd) to 1,967 mgd, with a median design capacity of 45 mgd. Nearly 60,000 permitted industries were accounted for in this survey.

The objectives of the survey were to:

1. Understand the prevalence of different types of industries that contribute to WWTP collection systems.
2. Understand the general framework for pretreatment programs.
3. Identify if there are industries or contaminants that pose consistent challenges.

A more detailed review of survey responses is provided in Chapter 3 of this report and the individual survey responses are provided in an anonymized excel database in Appendix B.

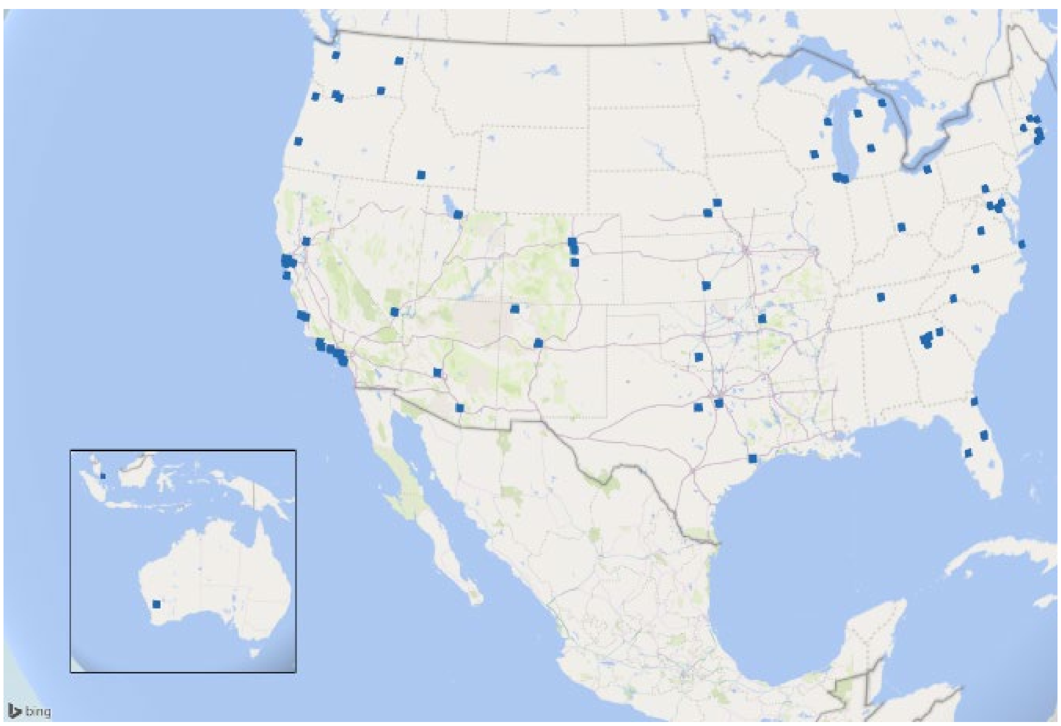

Figure ES-6. Map of Study Respondents.

Note: 80 utilities in the United States, Singapore, and Australia responded to the survey.

ES.5.1 Characteristics of Surveyed Utilities

Of the 80 utilities surveyed, 17 utilities responded that they participate in a potable reuse program, although only eight utilities have a currently operational potable reuse facility (including two demonstration-scale facilities; see Figure ES-7 for potable reuse flows as a percentage of the total average WWTP flow). The results of the survey were therefore heavily skewed toward utilities that are not currently practicing potable reuse and may reflect perspectives from conventional pretreatment programs rather than ESCPs. Where relevant, the survey differentiates answers between the utilities that are currently operating potable reuse facilities.

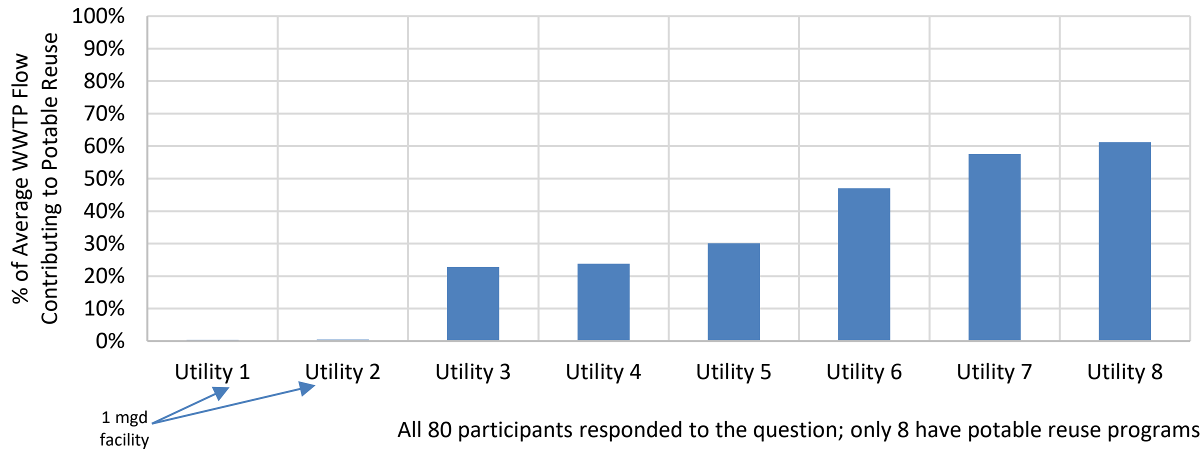

Figure ES-7. Percent Relationship between Potable Reuse Flows and Average WWTP Flows for the Utilities that Participate in Potable Reuse.

Another helpful metric from the survey was to assess what percentage of total discharge flow typically comes from industrial dischargers. Figure ES-8 shows the ratio between the average industrial user flow and the monthly average plant flow. The median value was 2.75 percent, with one utility as high as 43 percent. Most utilities had a ratio of less than 10 percent, showing that residential and non-permit-requiring commercial flows are typically significantly higher volumetric contributors to the influent flow.

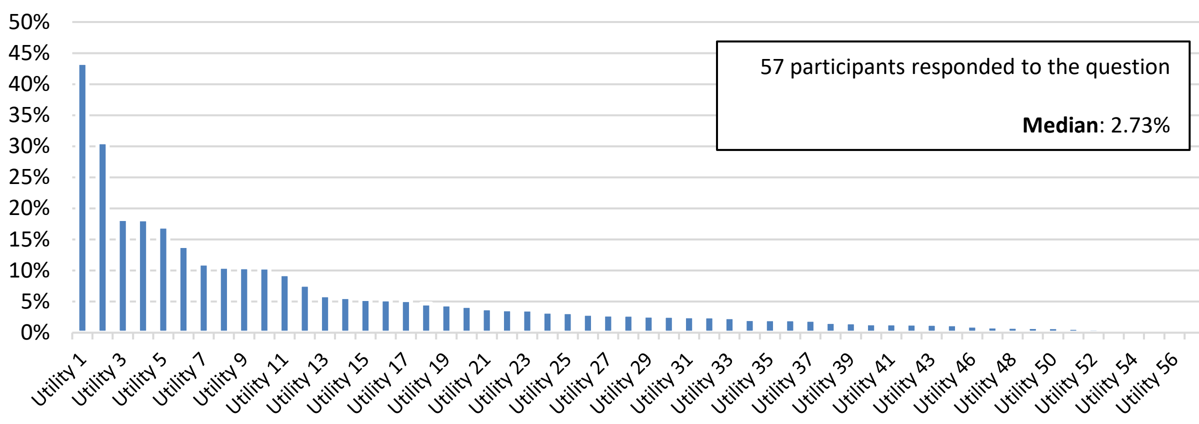

Figure ES-8. Relationship between Industrial User Flow and Monthly Average Plant Flow Per Utility.

ES.5.2 Challenging Industries

The first stated objective of the survey was to identify the types of industries that contribute to WWTP systems and identify the industry types that are the biggest challenge to utilities. Figure ES-9 shows the number of utilities (out of the 73 that responded to the question) that have permits for various industrial categories, with metal finishing, food processing, and landfills the most common. Figure ES-10 shows the types of industries that present the biggest challenge to utilities based on the impact to WWTP performance. Metal finishing was still the highest response, but interestingly, centralized waste treatment (CWT) facilities received the second most votes. Out of the 28 utilities that have permitted CWT facilities, 18 identified CWT facilities as the biggest challenge.

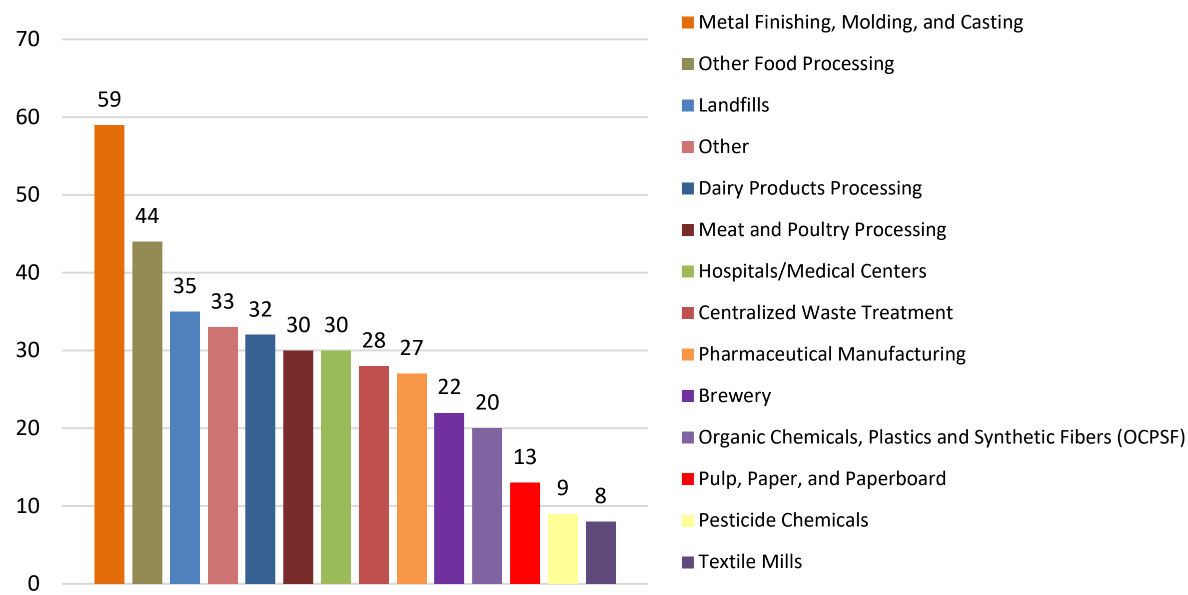

Figure ES-9. Types of Industries Included as Permitted Industrial Users.

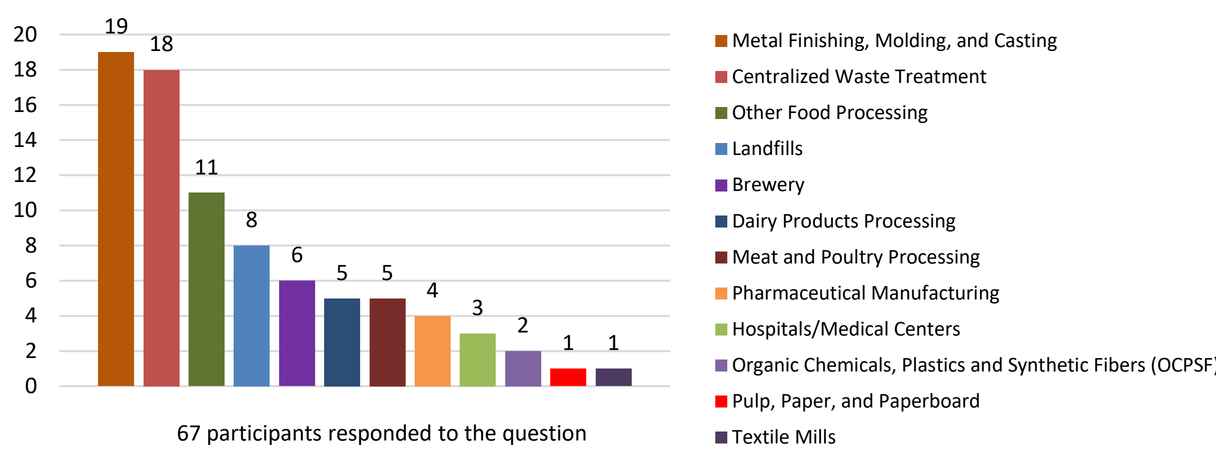

Figure ES-10. The Categories of Industrial Users that Present the Biggest Challenge to Utilities.

ES.5.3 Challenging Contaminants

The survey included several questions about specific contaminants or groups of contaminants that are the most challenging. Figure ES-11 shows the types of contaminants that present the biggest challenge to the participating utilities, with metals the most common answer. The trace organics category consisted of a wide array of specific contaminants that include PFAS, 1,4-dioxane, polychlorinated biphenyls, and microplastics, among others. Figure ES-12 shows the specific contaminants that were identified that impact treatment performance relative to One Water initiatives (the survey asked about One Water initiatives due to the small number of utilities specifically practicing potable reuse). While this was a separate survey question than what is shown on Figure ES-11, the responses reinforce that metals are the most common challenge, which should be viewed through the lens of a conventional pretreatment program that focuses on priority pollutants in accordance with National Pollutant Discharge Elimination System (NPDES) requirements. Figure ES-13 further emphasizes this trend, which shows the contaminants that have had local limits applied to support One Water initiatives. A total of 21 utilities responded that they had added local limits to support One Water programs, and metals were again the most frequent answers to this survey question.

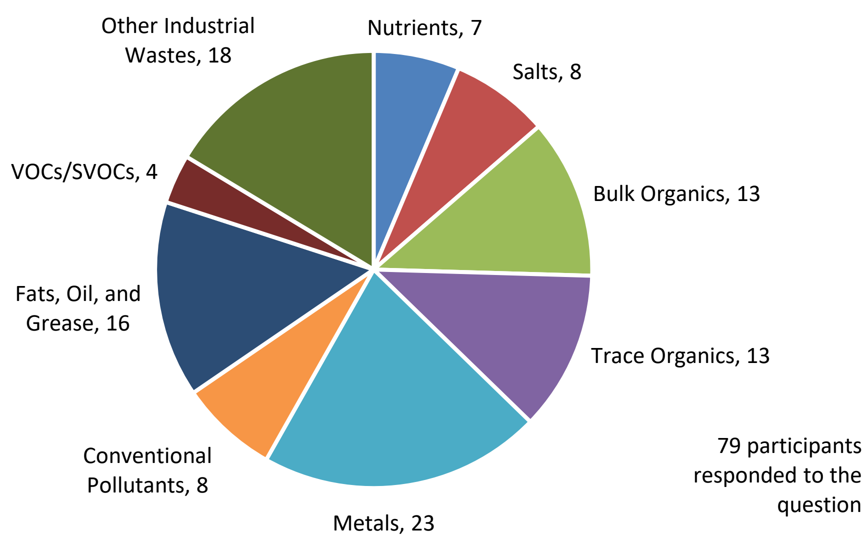

Figure ES-11. Types of Contaminants that Present the Biggest Challenge to Utilities.

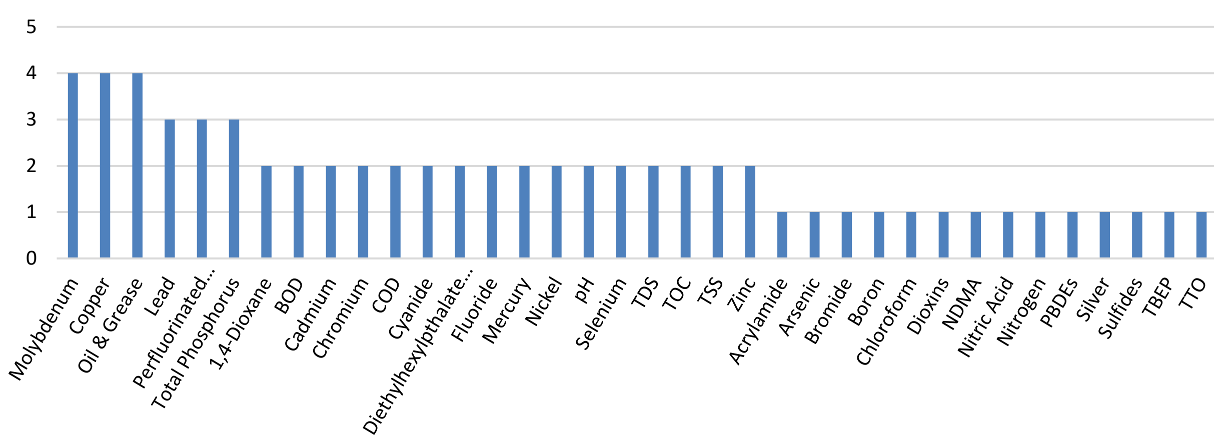

Figure ES-12. Contaminants that Impact Treatment Performance for One Water Initiatives.

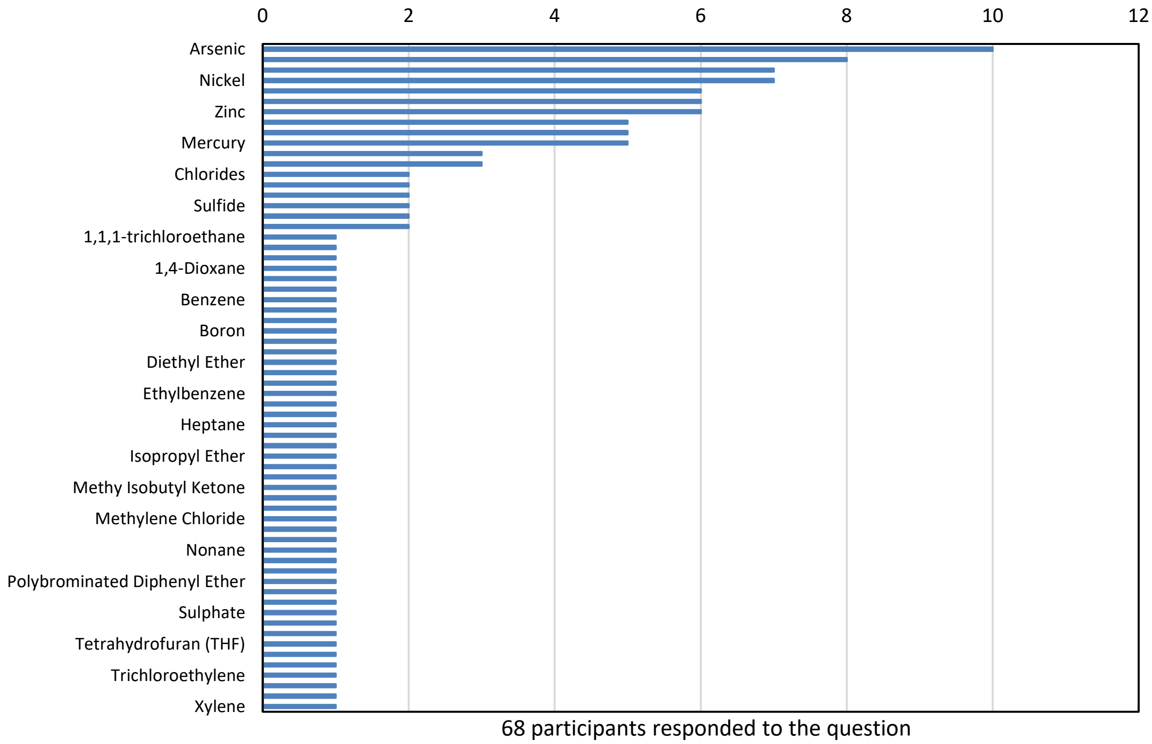

Figure ES-13. Contaminants that Had Site-Specific or Local Limits Applied Due to One Water Initiatives.

ES.5.4 Pretreatment Program Characteristics

Figure ES-14 shows the efforts utilities have included in their pretreatment program to better manage the challenges they face. This figure shows the answers to seven different yes/no questions with the solid blue bars representing how all utilities answered while the dotted red bars show how the utilities that currently practice potable reuse answered. This provides some general context on how utilities implement pretreatment programs and preliminary trends for the utilities that are practicing potable reuse. In general, Figure ES-14 emphasizes that more resources are needed for oversight, sampling, and implementation of ESCPs relative to conventional pretreatment programs.

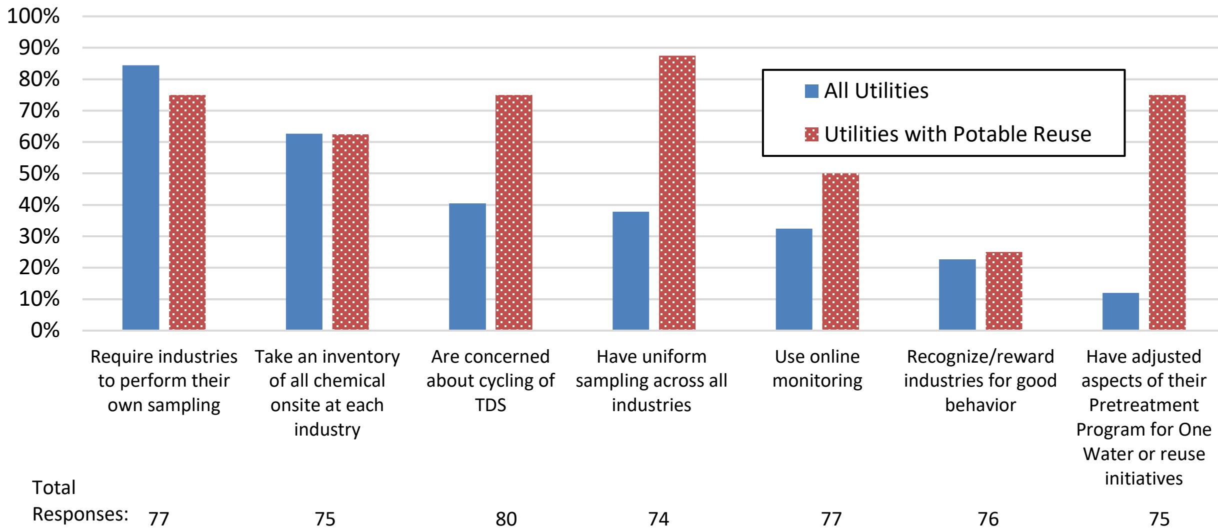

Figure ES-14. Frequency (in %) of Utilities with Various Pretreatment Features.

ES.6 Task 3: Potable Reuse Industrial Source Control Case Studies

In addition to the WWTP surveys that yielded broad answers, in-depth interviews were conducted with seven utilities to ask detailed questions about each program. The case studies focused on both small and large utilities that are in different stages of ESCP implementation and potable reuse program development. Interviews discussed specific industrial challenges and lessons learned for each utility, building on many of the questions asked in the survey. Table ES-4 lists the seven utilities, their relative size, and their level of source control program implementation at the time the interviews were conducted.

Table ES-4. Utilities Included in Case Study Interviews.

Utility and Purification Treatment Train	Purification Treatment Train	Potable Reuse Project Status	Treatment Plant Size		Level of Implementation of Source Control
			Small (<5 mgd)	Large (>5 mgd)	
Morro Bay, CA	MBR, RO, UVAOP	Under Construction	X		Limited Pretreatment Program, now initiating new ESCP
Pismo Beach, CA	UF, RO, UVAOP	Predesign	X		Limited Pretreatment Program
Santa Cruz, CA	UF, RO, UVAOP	Under Construction		X	Detailed Pretreatment Program
Altamonte Springs, FL	Ozone, BAC, GAC, UF, UV	Demonstration-Scale		X	Detailed Pretreatment Program
LACSD, CA	(Three systems) Tertiary Spreading, UF/RO/UVAOP then groundwater recharge (two facilities), and MBR/RO/UVAOP	Systems 1, 2, and 3 are operational, System 4 is demonstration-scale		X[a]	Detailed Pretreatment Program
HRSD, VA	Floc/Sed, ozone, BAC, GAC, UV	Under Construction & Demonstration-Scale		X[a]	Detailed Pretreatment Program with Robust ESCP
City of Palo Alto	Future UF, RO, UVAOP	Planning		X	Detailed Pretreatment Program

[a] These utilities operate multiple WWTPs.
Notes: LACSD = Los Angeles County Sanitation Districts, HRSD = Hampton Roads Sanitation District

Each case study interview was adapted to the utility based on their current program. However, the typical topics discussed included:

- Challenging contaminants affecting operation
- WWTP upsets and compliance
- Industrial dischargers
- Sewer use ordinances
- Enforcement response plans
- Monitoring programs
- Outreach efforts

A common thread across the case studies was that industry engagement and understanding the perspective and drivers of industries are keys to successful pretreatment programs and ESCPs. Chapter 4 documents each of the case studies and provides a summary of each interview in Table 4-12. The following key takeaways were common across the utilities interviewed:

- A robust enforcement authority is mandatory for long-term success.
- Early in the development of potable reuse programs, agreements or memoranda of understanding are needed between the leading water agency that will benefit from the new

recycled water and the wastewater utility that has experience and authority over the sewer collection system.

- Broad local limits can be applied to all permitted industries, but such an approach will result in overregulating some industries. Targeted limits are the most efficient way to impose limits on industry (see section 5.3.1).
- Direct and repeated engagement of industry is needed so that they are keenly aware of the need for the potable reuse project as well as their role in protecting water quality.
- There is no “ideal” industry, as there is no “typical” bad actor. Industries that discharge challenging contaminants have shown to be good partners on potable reuse projects in many cases. Seemingly benign industries have been shown to be challenging partners on potable reuse projects in some cases.
- A robust engagement and monitoring program for industry, as associated with potable reuse, should begin at least 12 to 24 months ahead of potable reuse production and carry on through the life of the project.
- In total, a robust and vigilant ESCP is necessary for every program, even those with little industrial influence (if this is the case, the ESCP will be largely focused on residential and commercial dischargers which was not covered in this project).

Several of the utilities interviewed were asked to estimate the cost of developing their ESCP (full ESCP, not just Industrial ESCP). This was a challenging question to answer as many of the increases of resources are difficult to quantify. Several responses are summarized in Table ES-5 with the high-level assumptions used to develop the estimates. In general, it seems the cost for a small utility that is not regulated by the NPP to go from a small pretreatment program to an ESCP is significant, requiring new staff and monitoring equipment. However, the incremental cost for a large utility that already has a robust pretreatment program may be moderate compared to the overall pretreatment program budget. Costs for large utilities developing ESCPs seem focused on additional analytical monitoring as it does not require significantly more resources or individual sampling events.

Table ES-5. Summary of Estimated Costs to Implement an ESCP.

Utility	Total Average WWTP Flow (mgd)	Number of Permitted Industries	Estimated Additional Cost to Implement ESCP	Notes
City of Morro Bay	0.8 mgd	0 (not regulated by NPP)	>$215,000 per year	Estimated annual costs of transitioning from a FOG program only to an ESCP are approximately $150,000 in personnel costs, $60,000 in new monitoring equipment, and laboratory costs of $5,000.
City of Santa Cruz	6 mgd	450	$100,000 per year	Costs for upgrading NPP to ESCP are focused on analytical costs for new contaminants. Additional monitoring costs are estimated at $75,000/yr. and require an estimated additional personnel cost of $25,000/yr. Pretreatment team consists of 3 FTE and has an annual budget of $880,000.
LACSD	390 mgd	2,006	$150,000 per year	Robust industrial waste program consists of 65 FTE and has an annual budget around $15 million. The majority of the resources are for baseline industrial pretreatment. Additional costs to support the ESCP include sampling for MCLs and CECs at the influent and effluent of each WWTP and source control investigations for NDMA, PFOA, and other contaminants. No staff were hired specifically to support the ESCP.
HRSD	250 mgd	175	$440,000 per year	Current ESCP (fully implemented for one of HRSD's 7 WWTPs that will be involved in SWIFT) has increased the pretreatment inspection team from 6 FTE to 7 FTE, at a cost of $90,000/year. SWIFT has required significant analytical costs but has not resulted in additional monitoring events. The estimated annual cost at the 1 WWTP where SWIFT is currently implemented is $100,000/year. The total analytical cost for all 7 WWTPs is $350,000/year. The annual budget for HRSD's pretreatment team is around $2.8 million.

Notes: > = greater than; /yr. = per year; CEC = contaminant of emerging concern; FOG = fats, oil, and grease; FTE = full-time equivalent

ES.7 Task 4: Develop Enhanced Source Control Program Framework

The results of the state-of-knowledge review, survey, and case studies led to the development of a step-by-step framework for utilities implementing Industrial ESCPs. Existing publications that recommend industrial elements of ESCPs were also reviewed and considered. The intent was to provide steps for utilities to implement an Industrial ESCP, which would then be incorporated into the larger ESCP.

The proposed framework includes 13 steps separated into four phases based on the approximate timing that each step should occur relative to the potable reuse project. While the recommended timing of each phase may vary depending on the size of the project, the intent was to help identify which tasks need to be completed prior to committing significant resources to the project (Phase 1), tasks that need to be completed prior to design of the advanced treatment facility and other associated infrastructure (Phase 2), and tasks that can be completed during design or construction (Phases 3 and 4). Figure ES-15 shows the four phases of the framework and the recommending timing. At the end of this chapter, Figure ES-21 provides the full framework.

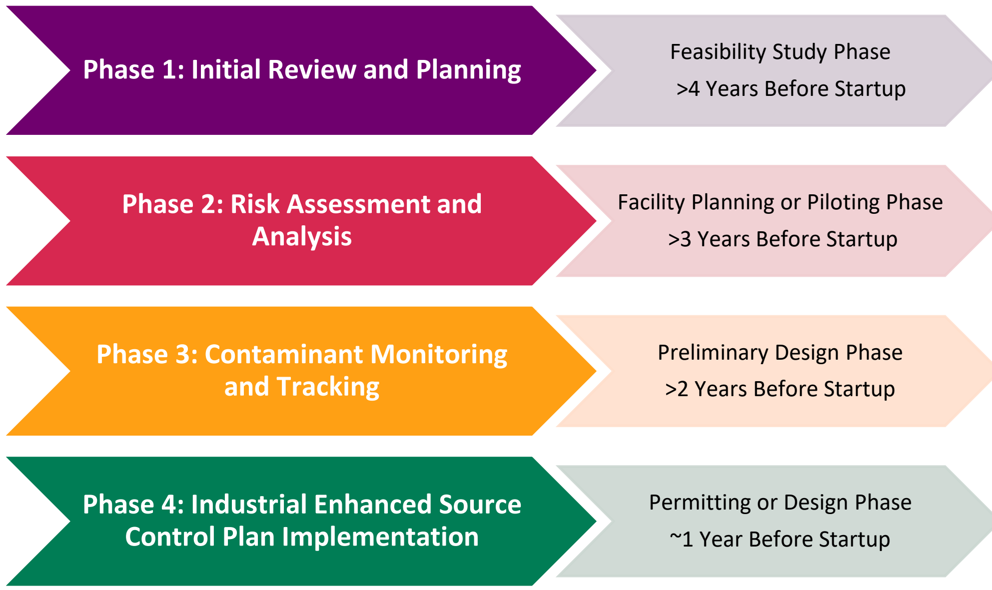

Figure ES-15. Phases of the Industrial Enhanced Source Control Program Framework.

ES.7.1 Phase 1: Initial Review and Planning

Initial Review and Planning

1. Review existing National Pretreatment Program authority
2. Identify partner agencies, begin interagency discussions, and consider stakeholder engagement and public outreach plans
3. Review existing industrial pretreatment program
4. Identify Technical, Managerial, and Financial (TMF) Capacity
5. Identify contaminants to monitor and begin WWTP sampling program

- Regulated drinking water contaminants
- Industrial contaminants with special concern for potable reuse
- Contaminants known to be a challenge for the utility
- Pass-through hazards, interference hazards, and the highest ICSS contaminants for the selected AWT train

Feasibility Study Phase (>4 years before project)

Figure ES-16. Initial Review and Planning.

Figure ES-16 lists the five steps of Phase 1 which is intended to set the foundation for the Industrial ESCP. These are all high-level steps that should occur during the feasibility study phase, ideally four or more years prior to project startup of full-scale facilities. These steps are critical to the development of the Industrial ESCP, the full ESCP, and the potable reuse project as a whole, and should be initiated prior to committing significant resources. The Phase 1 activities can mostly be performed in parallel but should be completed before Phase 2 is initiated. It is recommended that the utility develop an ESCP feasibility study report that summarizes the results of the steps in Phase 1 prior to proceeding to Phase 2. Section 5.1 provides more detailed discussion on the steps recommended in Phase 1.

Through steps 1 and 2 of the framework, the utility will identify the legal authority for implementing and enforcing the ESCP. This includes the development of permitted limits that support the potable reuse program, which is arguably the most challenging to implement and controversial (particularly for interagency agreements) aspect of the ESCP. The NPP provides utilities with the authority to implement limits for contaminants that are of local concern, which can be interpreted to include potable reuse. However, the NPP lists specific beneficial uses for which local limits can be implemented and potable reuse is currently not a specified use. This provides some uncertainty to how local limits would hold up in state or higher courts if they were challenged. It is important that the utility work with the appropriate state and federal entities to find alignment on implementing limits early in the project. It is also important that, when the utility does implement limits, the limits are defensible and data-driven so that they have low risk of being challenged by industries.

A key outcome of Phase 1 is the identification of contaminants that should be included in the WWTP sampling program. This provides an opportunity to identify challenging industrial contaminants in the system and should be performed in tandem with the WWTP sampling that is needed for the selection and design of advanced treatment technologies. The following groupings of contaminants should be included in the initial WWTP sampling program:

1. Regulated contaminants for the potable reuse project, likely, including USEPA primary MCLs.
2. Industrial contaminants with special concern for potable reuse projects, including 1,4-dioxane, nitrosamines (NDMA and NMOR at a minimum), PFAS (those that have local, state, or federal regulatory relevance, and those that have published toxicological metrics), relevant low molecular weight compounds (i.e., formaldehyde and acetone), contaminants with potential for disinfection byproduct formation (bromide), and contaminants with potential for interference (iron, manganese, hardness, etc.).
3. Contaminants known to be a challenge for the utility, including contaminants that have caused WWTP challenges, contaminants that have caused collection system challenges, or contaminants that are known to be discharged by problematic industrial dischargers.
4. Pass-through hazards, interference hazards, and the top ICSS contaminants for the selected advanced water treatment (AWT) train.

ES.7.2 Phase 2: Risk Assessment and Analysis

Phase 2, which includes steps 6 through 8 and is shown in Figure ES-17, is intended to identify and quantify potential industrial contaminant risk to the potable reuse system. This phase identifies the industrial contaminants that have the highest risk to the potable reuse system, both from chemical spills and from background concentrations. As such, it is important that these steps be completed prior to the start of design of the advanced treatment facility. A document summarizing the contaminant risks and mitigation strategies should be developed at the end of Phase 2.

RISK ASSESSMENT AND ANALYSIS

6. Identify industrial risks
   - Create a chemical inventory for all industries and list existing control measures
   - Perform site-specific sampling at industries that are known to be a challenge
7. Perform risk analysis using the ICSS framework and measured contaminant concentrations
8. Evaluate, document, and mitigate system risk

Facility Planning Phase (>3 years before project)

Figure ES-17. Risk Assessment and Analysis.

An important feature of Step 6 is the development of a chemical inventory at each industry. This provides an understanding of the different chemicals that are used and discharged by each industry and can identify if additional sampling or research is needed on any individual contaminant. Also part of Step 6 is sampling at each industry which can be compared with sampling performed in Step 5 to identify the industrial dischargers that contribute meaningful loads of each of the identified challenging industrial contaminants. This allows for site-specific discussions to begin and the development of contaminant monitoring strategies.

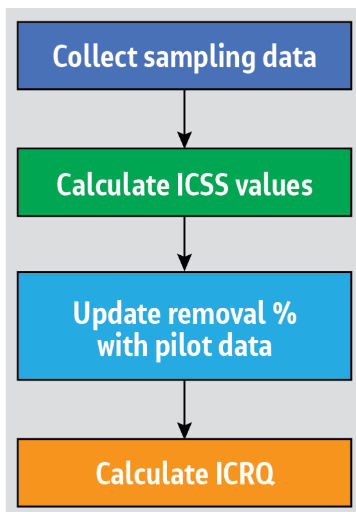

Figure ES-18. ICRQ Flowchart.

During this phase it is also recommended to use the sampling data from Step 5 to conduct a risk assessment using the ICSS data discussed in Task 1. ICSS values should be gathered for all sampled contaminants for which there is an ICSS value. Then, if the project has compiled site-specific contaminant removal values based on pilot testing or other testing, the ICSS values should be updated as many of the percent removal values in the ICSS calculation are conservative. This step will provide updated ICSS values that can then be used to calculate an Industrial Contaminant Risk Quotient (ICRQ), the risk of each contaminant (ICSS only suggests a potential hazard; once the ICSS value is paired with site-specific sampling, the risk of each contaminant can be calculated). Figure ES-18 provides a flowchart of these steps for quick reference and Equation ES-2 shows the formula for calculating the ICRQ which combines the ICSS value with the sampling data.

$$ICRQ = C\ in \frac{mg}{L} * \frac{2\ L}{day} * \frac{adult}{70\ kg} * \frac{1}{20\%} * ICSS$$ **Equation ES-2**

In Equation ES-2, ICRQ is unitless, C is the average concentration of the contaminant in the wastewater in mg/L (if wastewater effluent is used, the ICSS should be updated to remove the impact of wastewater treatment), 20% is the default Relative Source Contribution (RSC; see Chapter 5 for discussion), and the ICSS is the ICSS value in kilograms*days per milligrams.

It is recommended that an ICRQ value greater than 0.2 triggers the development of a pollutant tracking strategy and ongoing monitoring of the contaminant. An ICRQ greater than 1.0 suggests that the contaminant could be in the AWTP effluent at concentrations above the recommended health level. This should trigger discussion on additional treatment steps or ways to reduce the source loading so that the ICRQ is consistently below 1.0.

Table ES-6 provides two examples of calculated ICRQ values using hypothetical concentrations of 1,4-dioxane and PFOS detected in a secondary or tertiary treated effluent. These provide examples for how to use the ICSS and ICRQ frameworks. These examples show that the 1,4-dioxane concentration would need to be 12.4 micrograms per liter (µg/L) in the WWTP influent to result in an ICRQ above 0.2 for Train A. Similarly, the PFOS concentration in the WWTP influent would need to be 0.186 µg/L to result in an ICRQ above 0.2 for Train B.

Table ES-6. Two Example IC Risk Quotients.

Parameter	Example 1	Example 2
Contaminant	1,4-dioxane	PFOS
Treatment Train	A (RO-based)	B (GAC-based)
WWTP Influent Sample Concentration[a]	2.0 µg/L	0.05 µg/L
Assumptions to Calculate USEPA HALs[b]	Avg. consumption: 2 L/day; Avg. wt. per adult: 70 kg; RSC Correction factor: 20%	
ADC	[0.002 mg/L *2 L/day / 70 kg/adult / 20%] = 0.000286 mg/kg/day	[0.00005 mg/L *2 L/day / 70 kg/adult / 20%] = 0.000007 mg/kg/day
ICSS[c]	113 days * kg/mg	7,500 days * kg/mg
ICRQ = (ADC*ICSS)	0.03	0.05
Value in WWTP Influent to Trigger Ongoing WWTP Source Monitoring (ICRQ >0.2)	12.4 µg/L	0.186 µg/L
Value in WWTP Influent to Trigger Source ID and Risk Reduction (ICRQ >1.0)	62 µg/L	0.93 µg/L

[a] For reference, California drinking water NL are 1.0 µg/L for 1,4-dioxane and 0.0065 µg/L for PFOS. The USEPA lifetime HA levels are 200 µg/L for 1,4-dioxane and 0.070 µg/L for PFOS.

[b] Assumes typical USEPA lifetime Health Advisories assumptions: an average adult weighs 70 kg, consume 2 liters of water per day, 20% of a person's intake of this chemical comes from water.

[c] If pilot testing shows a higher percent rejection for a treatment train, the ICSS would reduce, which would result in a lower ICRQ for a given sample concentration.

Notes: ADC = Adult Dose Correlation; HA = health advisories; kg/mg = kilogram(s) per milligram

ES.7.3 Phase 3: Contaminant Monitoring and Tracking

The focus of Phase 3, which includes Steps 9 through 11 and is shown in Figure ES-19, is to monitor contaminants in the collection system and develop source tracking plans. Phase 3 is recommended to be performed in parallel with design as there should not be any new information identified in Phase 3 that would significantly affect the design of the AWTP. Step 11 includes submitting the Industrial ESCP (as part of the larger ESCP) for permitting approval, if required by a regulatory agency, which should also occur in parallel with design.

CONTAMINANT MONITORING AND TRACKING

9. Perform industry sampling to identify sources of contaminants
   - Calculate load-based contributions of contaminants by discharger
   - Establish site-specific and local limits, as needed
   - Consider isolating or eliminating specific industrial dischargers
   - Draft pollutant tracking strategy
10. Develop robust sampling and monitoring plan
11. Finalize Industrial ESCP for permitting and implementation
   - Revisit TMF Goals based on identified risks and additional sampling and monitoring requirements

Preliminary Design Phase (>2 years before project)

Figure ES-19. Contaminant Monitoring and Tracking.

Step 9 is where industries are directly engaged to discuss mitigation strategies for the contaminants of concern (ICRQ>0.2) identified in Phase 2. This step explains how to identify the industrial dischargers that are significant contributors of the contaminant and recommends working with each industry that has greater than 5 percent contribution on a load basis. If the utility is working toward establishing a limit for a specific discharger, they should do so based on the sampling at the WWTP and the amount of the contaminant that needs to be reduced to be comfortably and consistently below the finished water target. Developing limits can be a challenging and lengthy process and it is important that it is data-driven and targeted at the dischargers that are meaningful contributors.

While Step 9 outlines how to work with specific industrial dischargers, this is also a key period for stakeholder engagement with all industries so that they are aware of the project and the approaches that are being taken to protect public health and mitigate the discharge of harmful contaminants. The contaminants of concern identified in Phase 2 can be communicated to all industries so that they are aware of the focus of the ESCP.

ES.7.4 Phase 4: Industrial ESCP Implementation

As the AWTP approaches startup, it is important to begin integrating the ESCP, both industrial and non-industrial components, into the project and implementing the program, which is Phase 4, the final phase of the framework. Figure ES-20 lists the steps of Phase 4.

INDUSTRIAL ESCP IMPLEMENTATION

12. Implement an Industrial ESCP Advisory Team
13. Implement Industrial ESCP

- Annual evaluation, audit, and continuous improvement plan
- Monitoring, responses, and corrective action plans for contaminants of concern
- Stakeholder management, communication protocols, and enhanced public education outreach
- Documentation and reporting
- Communication and recognition plans for industries

Permitting or Design Phase (~1 year before project)

Figure ES-20. Industrial ESCP Implementation.

This phase includes implementing an Industrial ESCP Advisory Team, which should include key project stakeholders for all represented agencies, and certainly members representing the pretreatment program, wastewater treatment, advanced treatment, and regulatory compliance. This team should meet quarterly for the duration of the project to audit the Industrial ESCP, including reviewing the contaminants of concern, response protocols, and relationships with industries, among others. It is recommended that the Industrial ESCP Advisory Team be incorporated into the larger ESCP Advisory Team that includes non-industrial representatives of the ESCP.

Implementation of the Industrial ESCP is essentially a repetition of Steps 5 through 10 and requires a focus on continuous improvement. It involves continually identifying what contaminants might pose a risk to the potable reuse system, locating key sources, and finding ways to reduce or eliminate the discharge of the contaminants. It involves constant communication with other stakeholders. It involves building strong, trusted relationships with the industries that are now a closer part of the drinking water cycle. The Industrial ESCP is never finished but as each year passes the roles and responsibilities should be more defined and, hopefully, the challenges encountered will be increasingly diminished.

ES.7.5 Recommended Next Steps

While a total of 262 industrial contaminants were identified and evaluated for health and AWTP pass-through risks, a fully comprehensive evaluation was not possible. This was due to the magnitude of contaminants in existence, the lack of knowledge (both toxicology and treatability) on these contaminants, and the lack of information on industrial dischargers. While this report was able to include a significant number of contaminants, there is still more work to be done. The following areas are recommended for future research to further improve the recommended Industrial ESCP approach:

- Contaminant toxicology: prioritize the toxicological evaluation of existing and emerging contaminants so that sampling plans can target the highest potential hazards.
- Contaminant fate through treatment: improve the understanding of the fate of existing and emerging contaminants through different advanced treatment processes.
- Contaminant sourcing: collect samples across a variety of industrial users and identify the

contaminants that are typically discharged by different types of industries. This is relatively well-known for pretreatment and conventional wastewater treatment purposes but contaminants relevant for potable reuse are not well understood and linked to industries.

- Industrial contaminants: this project evaluated the impact of 262 industrial contaminants that have been identified by different regulations, guidelines, or lists. However, this effort does not encompass all of the industrial chemicals that are discharged into wastewater collection systems. A more comprehensive effort is needed to identify all contaminants used or discharged by major industries and the toxicological impact and treatability of each contaminant. While this may not be possible to do for all industries, it may be possible for a single utility or collection system.
- Framework for non-industrial dischargers: this project focused only on industrial dischargers. However, a full ESCP will include considerations for residential and commercial dischargers. A robust framework for developing these aspects of the ESCP would be beneficial to the industry.
- Recommendations for challenging industries: there are a small number of industrial categories that present a disproportionate risk to potable reuse systems, including metals finishing, landfills, and CWTs, as identified in the potential sources of hazard contaminants and the results of the survey and case studies. Specific research should be conducted on these three industries to develop uniform recommendations for how utilities should approach an ESCP if these industries are in its collection system.
- Compilation of best practices: as more utilities begin operating potable reuse systems, a compilation of best practices and lessons learned for ESCPs would be valuable for the industry. While this project included case study interviews, only two utilities interviewed have operational potable reuse systems. Once more utilities have systems online (in 5 or more years), a comprehensive summary of best practices and lessons learned from 10 to 20 utilities with ESCPs would be helpful to the industry.
- Roadmap for local limits implementation: one of the most challenging topics for ESCPs is how local limits will be implemented. It would be helpful for the industry to have a document that (1) details case studies at 5-10 locations where local limits were implemented to support potable reuse projects, including how the limit was developed and the response by the industry; and (2) summarizes the legal authority of different states in implementing local limits for potable reuse as this varies across the United States. A consolidated document would help new projects and states understand how local limits are being implemented for potable reuse projects across the country.

Initial Review and Planning

1. Review existing National Pretreatment Program authority
2. Identify partner agencies, begin interagency discussions, and consider stakeholder engagement and public outreach plans
3. Review existing industrial pretreatment program
4. Identify Technical, Managerial, and Financial (TMF) Capacity
5. Identify contaminants to monitor and begin WWTP sampling program

- Regulated drinking water contaminants
- Industrial contaminants with special concern for potable reuse
- Contaminants known to be a challenge for the utility
- Pass-through hazards, interference hazards, and the highest ICSS contaminants for the selected AWT train

Feasibility Study Phase (>4 years before project)

Risk Assessment and Analysis

6. Identify industrial risks

- Create a chemical inventory for all industries and list existing control measures
- Perform site-specific sampling at industries that are known to be a challenge

7. Perform risk analysis using the ICSS framework and measured contaminant concentrations
8. Evaluate, document, and mitigate system risk

Facility Planning Phase (>3 years before project)

Contaminant Monitoring and Tracking

9. Perform industry sampling to identify sources of contaminants

- Calculate load-based contributions of contaminants by discharger
- Establish site-specific and local limits, as needed
- Consider isolating or eliminating specific industrial dischargers
- Draft pollutant tracking strategy

10. Develop robust sampling and monitoring plan
11. Finalize Industrial ESCP for permitting and implementation

- Revisit TMF Goals based on identified risks and additional sampling and monitoring requirements

Preliminary Design Phase (>2 years before project)

Industrial ESCP Implementation

12. Implement an Industrial ESCP Advisory Team
13. Implement Industrial ESCP

- Annual evaluation, audit, and continuous improvement plan
- Monitoring, responses, and corrective action plans for contaminants of concern
- Stakeholder management, communication protocols, and enhanced public education outreach
- Documentation and reporting
- Communication and recognition plans for industries

Permitting or Design Phase (~1 year before project)

Figure ES-21. Enhanced Source Control Framework.

ES.8 Related WRF Research

- Hospital Wastewater Practices and Compounds of Emerging Concern in Water (4616)
- Operational, Monitoring, and Response Data from Unit Processes in Full-Scale Water Treatment, IPR, and DPR (4767)
- Demonstrating Redundancy and Monitoring to Achieve Reliable Potable Reuse (4765)

CHAPTER 1

Introduction

The goal of this project was to identify industrial contaminants that can impact potable reuse treatment and recommend mitigation strategies. The project was funded through the State Water Resources Control Board in California (SWRCB) Grant and the Advancing Potable Reuse Initiative that leverages the grant. These fund research to advance potable and non-potable reuse in California and across the world.

This project consisted of a literature review, a broad utility survey, and detailed case studies. The results of these efforts were used to develop a proposed framework for utilities to implement Industrial Enhanced Source Control Programs (ESCPs) that would be incorporated into a holistic ESCP that includes considerations for residential and commercial dischargers. The goal of the framework is to provide a uniform set of guidelines for utilities to follow that will result in reduced risk in the implementation and operation of potable reuse projects.

1.1 Research Approach

The project objectives identified by The Water Research Foundation (WRF) and the SWRCB were to:

1. Identify contaminants or families of contaminants related to industry or manufacturing and review the types of industries that may consume or discharge these contaminants.
2. Group listed contaminants in terms of risk to water quality and impact to advanced treatment.
3. Develop mitigation strategies, including treatment, inspection, and monitoring.

This project was broken down into the following four tasks to achieve the project objectives:

- Task 1: Conduct a state-of-knowledge review of industrial contaminants that impact potable reuse operation, their toxicity, and the types of industries that discharge these contaminants.
- Task 2: Survey a wide range of wastewater treatment plants (WWTPs) to understand the prevalence of different industries, common challenge contaminants, and features of existing pretreatment programs.
- Task 3: Perform detailed case study evaluations of existing pretreatment programs and ESCPs that are either currently in operation, or will be in the near future, to identify best practices, risks of specific industries, and potential gaps.
- Task 4: Develop a step-by-step framework for utilities to develop an Industrial ESCP based on best practices and mitigation strategies determined in Tasks 1 through 3.

As shown on Figure 1-1, Tasks 1 through 3 were developed in coordination so that lessons learned from each task could be applied and integrated into the other tasks. For example, contaminants identified by utilities in Tasks 2 or 3 were added back to the state-of-knowledge review before it was finalized. After Tasks 1 through 3 were completed, Task 4 was initiated.

Task 4 summarizes the best practices for mitigating the risk of industrial contaminants and recommends a framework for Industrial ESCPs. Each of the main tasks of the project has a summary chapter in this report.

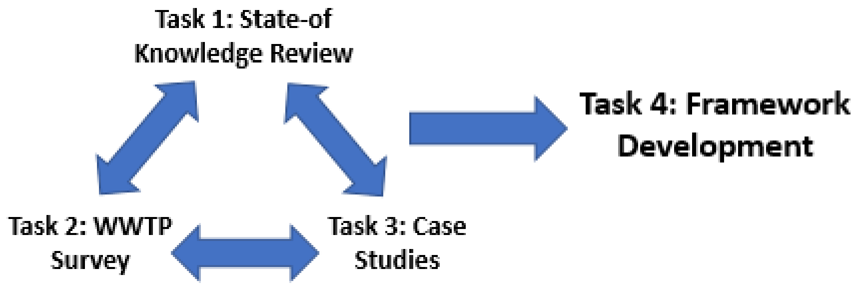

Figure 1-1. Task Flow Chart.

1.1.1 Project Scope

ESCPs for potable reuse projects require an evaluation and understanding of all contributors to the collection systems. There are often separate programs targeted at industrial, commercial, and residential customers. These are all important aspects of ESCPs, but the focus of this project is specifically on industrial contaminants. Thus, this project identifies a framework for an industrial-focused ESCP, which is referred to as an Industrial ESCP throughout this report. It is acknowledged and recommended that the Industrial ESCP needs to be incorporated into a full ESCP that includes considerations for residential and commercial dischargers.

The recommendations provided in this report for Industrial ESCPs are primarily directed toward significant industrial users (SIUs) as defined by the National Pretreatment Program (NPP) and summarized in Section 1.2.1. The terms industrial discharger or industrial user can cover different ranges of industries depending on the utility; therefore, this report focuses specifically on SIUs. Each utility of course can apply the recommendations to additional industries as it sees fit.

Another scope clarification is that this project does not distinguish between direct potable reuse (DPR) and indirect potable reuse (IPR). Most of the recommendations in this report are relevant for both types of systems, though it is acknowledged that the monitoring and response plans for DPR systems should be more robust than for IPR systems. In some cases, this report does discuss implications specific to DPR but in most cases the research and recommendations are applicable to both DPR and IPR.

The project team focused on the industrial contaminants that pose the biggest health risk to potable reuse systems, whether by pass-through or interference. The team did not consider contaminants that cause challenges for residuals management and subsequent discharge.

Many utilities or municipalities have developed One Water plans for their communities that identify the many connected aspects of the water cycle. This can be valuable for planning purposes and for public engagement. Potable reuse is often considered one aspect of One Water programs, along with non-potable reuse, resource recovery, stormwater management, and many others. This report acknowledges larger One Water programs in some areas, but the primary focus is specifically on potable reuse.

1.2 Project Background

Successful potable reuse systems require effective pretreatment and source control programs that address residential, commercial, and industrial flows entering the wastewater collection system. Industrial dischargers may present significant risk due to the types of contaminants used in industrial processes, the potential for variability in discharge quality, and the higher point source flows relative to residential and commercial users. The goal of source control programs is to keep difficult-to-treat or otherwise problematic contaminants from entering the collection system.

Establishing definitions for industrial pretreatment, conventional source control programs, and ESCPs is important to understanding this report. This project focuses on ESCPs, and specifically industrial-focused ESCPs, and provides recommendations for utilities to enhance existing pretreatment programs to meet the potable reuse program needs. The term ESCP is currently used within the industry to designate a program that is focused on potable reuse. The report is mostly focused on ESCPs, but also discusses elements of existing pretreatment programs.

Pretreatment Program: Activities associated directly with the National Pretreatment Program requirements (40 CFR § 403). The focus is on industrial monitoring and pretreatment.
Source Control Program: Activities under a Pretreatment Program associated with limiting the discharge of contaminants into a wastewater collection system that can impact wastewater treatment or resource recovery.
Enhanced Source Control Program: Enhancements to a source control program that are enacted specifically focusing on potable reuse and public health.
Industrial Enhanced Source Control Program: A component of an ESCP that focuses exclusively on industrial dischargers.

1.2.1 National Pretreatment Program

The NPP was established in 1983 as part of the Clean Water Act to control and regulate the discharge of pollutants from commercial and industrial dischargers of wastewater to publicly owned treatment works (POTWs). The General Pretreatment Regulations are contained in *Code of Federal Regulations* Title 40, Part 403 (40 CFR § 403). They establish responsibilities of federal, state, and local government, as well as industrial dischargers, to implement pretreatment standards to control pollutants discharged from non-domestic sources. Since its inception, the NPP has been notably successful in reducing the discharge of pollutants into POTWs nationwide (Tchobanoglous et al. 2015). The overall objectives of the NPP (40 CFR 403) 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 municipal biosolids.
- Prevent the introduction of pollutants into a POTW that will pass through the treatment facility and exit the POTW and cause effluent or biosolids permit violations.

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

Utilities that operate a POTW with a capacity more than 5 million gallons per day (mgd), or a combination of POTWs with combined capacities greater than 5 mgd, and receive flows from industrial users are subject to NPP requirements and are required to develop an industrial pretreatment program. Some POTWs with flows less than 5 mgd can also be required to meet NPP requirements if the nature or volume of the industrial discharge can provide interference or pass-through challenges at the POTW (40 CFR 403.8(a))

Summary of key NPP points for this project:

- The NPP provides the regulatory authority for utilities to implement limits for contaminants that are a challenge to a reuse system.
- This project focuses on SIUs as those utilities have been identified to have the most risk to the POTW.

A POTW that is required to comply with the NPP becomes the Control Authority after developing and gaining approval for its local pretreatment program. The Approval Authority is either the U.S. Environmental Protection Agency (EPA) or the state (36 states are currently approved to act as the Approval Authority). The POTW then has the authority to develop limits that address interference or pass-through risks for the system. This could be for the protection of waterways, biosolids, water reuse projects, or other needs. This is particularly relevant for this project, as the NPP provides the authority for utilities to add limits for contaminants that are a challenge to reuse systems.

The NPP has developed categorical pretreatment standards that apply to a specific type of industrial user (IU) categories. These categorical pretreatment standards are technology-based (i.e., they are based on the performance of treatment and control technologies) and are applied to the regulated discharges from categorical industrial users (CIUs) to the POTW. The NPP also requires POTWs to identify and control SIUs, based on their local limits. These two classifications are described in the following bullets.

- SIUs are defined at 40 CFR 403.3(v). An industry is classified as a SIU if it meets any of the following:
  - Is subject to categorical pretreatment standards under 40 CFR 403.6 and 40 CFR Section I, Subsection N, except those designated as non-significant CIUs (NSCIUs).
  - Discharges an average of 25,000 gallons per day (gpd) or more of process wastewater to the POTW, excluding sanitary, noncontact cooling, and boiler blowdown wastewater.
  - Contributes a process waste stream that makes up 5 percent or more of the average dry-weather hydraulic or organic capacity of the POTW.

- Is designated as such by the POTW on the basis that the industrial user has a reasonable potential for adversely affecting the POTW's operation or for violating any pretreatment standard or requirement [in accordance with 40 CFR 403.8(f)(6)].

- CIUs are industries that are defined within 40 CFR 405 to 471. An industry is classified as a CIU if it can be described by any of the 59 identified categories.
  - CIUs are subject to categorical pretreatment standards that specify the quantity and concentration of pollutants that can be discharged to POTWs.
  - 35 of the 59 industrial categories include pretreatment standards for new sources and pretreatment standards for existing sources that provide technology-based standards for the industrial discharge.
  - A CIU is also designated as an SIU unless it qualifies as an NSCIU.
  - An NSCIU is defined in 40 CFR 403.3(v)(2) as a categorical industry that never discharges more than 100 gpd of categorical wastewater, has consistently complied with all pretreatment requirements, and never discharges any concentrated wastewater.

This project is primarily focused on the discharge of SIUs into POTWs that are part of potable reuse systems. SIUs, by definition, are industries that present a considerable risk to a potable reuse system, whether they also qualify as CIUs or not. It is assumed that NSCIUs do not contribute enough flow or contaminant load to merit focus during the initial phases of an ESCP.

1.2.2 Enhanced Source Control Programs

As shown in Section 1.2, an ESCP is a source control program that has been enhanced to specifically focus on potable reuse and public health. ESCP has become the industry standard term for potable reuse projects and these programs are essential to the ongoing success of the treatment systems. This project focuses on industrial contaminants and thus provides recommendations for how to establish the industrial aspects of the ESCP (or, the Industrial ESCP as it is referred to in this report). However, the Industrial ESCP needs to be incorporated into the rest of the ESCP (including considerations for residential and commercial dischargers) to fully support the project.

The NPP provides agencies implementing potable reuse the foundational elements needed to implement enhanced source control. In many cases, going from a well-designed NPP program to an ESCP may not require significant additional resources and may primarily consist of additional contaminants in the routine sampling programs. However, in cases where there is no industrial pretreatment program (where the NPP does not apply), there will need to be a significant focus on implementing the ESCP and dedicating resources to its success.

Some of the pollutants that are already controlled through local limits in a utility's NPP may also be relevant to the planning, design, and operation of the potable reuse system. However, it is likely that additional contaminants that are specific to drinking water (i.e., EPA primary maximum contaminant level contaminants) are not included in the existing NPP and need to be evaluated in the ESCP. Figure 1-2 provides a simple schematic that outlines how and when an NPP should be upgraded to an ESCP.

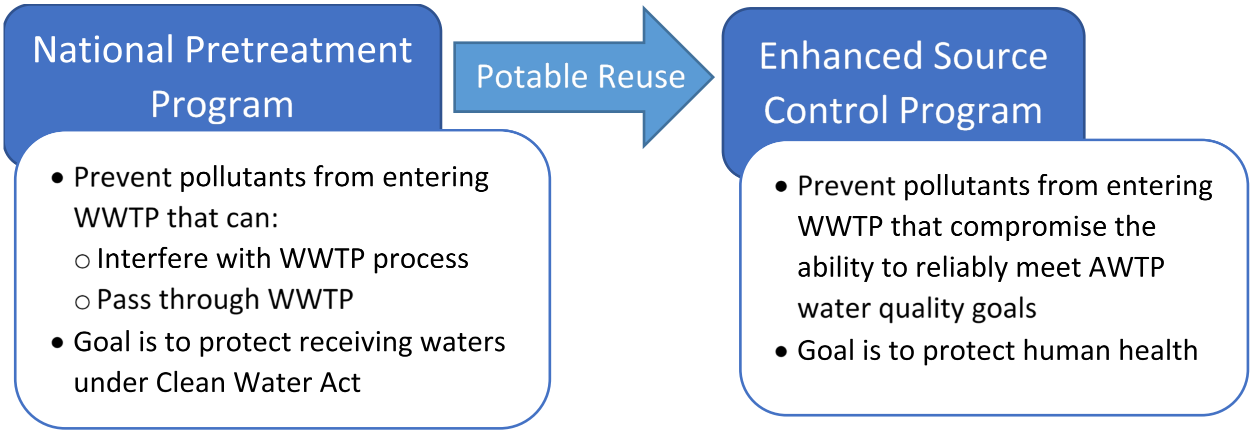

Figure 1-2. Overview of NPP and ESCP.

1.2.3 Importance to Potable Reuse

Potable reuse systems use advanced treatment technologies to provide multiple barriers of treatment for pathogens and chemical contaminants. Extensive work has been conducted to understand the pathogenic risk to potable reuse utilizing the quantitative microbiological risk assessment (QMRA) methodology. QMRA is used to predict the risk of infection from exposure to water produced by an advanced water treatment plant (AWTP) and studies for potable reuse have concluded that the risk can be reduced to below the benchmark of 1 in 10,000 risk of infection with high confidence (Salveson et al. 2018). The QMRA framework has been designed to provide adequate human health protection to the acute toxicity risk posed by pathogens during an outbreak or nonstandard operation; thus, AWTPs are designed with much more pathogen removal capability than is needed for typical operation.

Most chemical contaminants in water pose chronic health risks rather than acute (nitrate being one example of an acute risk) and regulated levels of contaminants in potable water are based on the chronic risks associated with consuming a steady dose spread over a lifetime. Limited work has been performed by the potable reuse community to understand the prevalence of chemical excursions in the collection system and the impact on potable reuse. Advanced treatment systems are not typically designed to treat concentrations that are significantly higher than average, leaving them susceptible to excursions.

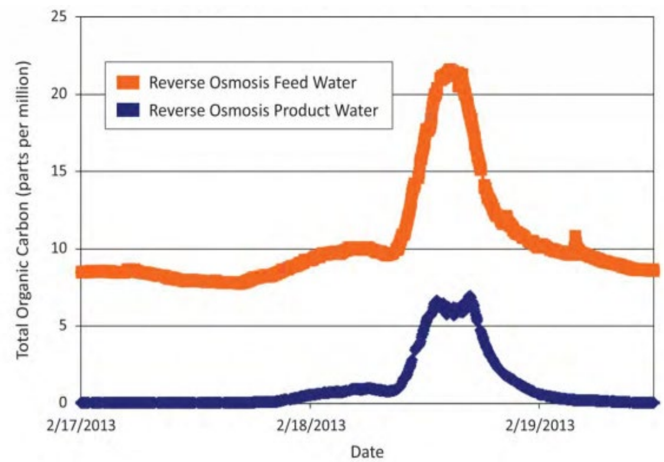

Figure 1-3. Real Time TOC Measurements at the Groundwater Replenishment System During an Acetone Event.
Source: Olivieri et al. 2016

Two primary examples of this have been seen in California, including abnormally high levels of gross beta discharged into the Oxnard collection system and acetone discharged into the Orange County Sanitation District (OCSD) collection system, both of which pass through reverse osmosis (RO) systems. Regarding Oxnard, the problem was tracked to the source, a centralized waste treatment facility, and the industry was shut down. OCSD has a robust ESCP, yet in 2013, the collection system experienced a slug of acetone from an industry as determined by online monitoring of total organic carbon (TOC) and later identified as acetone (Figure 1-3). Finished water TOC concentrations exceeded 5 milligrams per liter (mg/L) for several hours. While this was not a public health concern, it highlights the risk of industrial contaminants to potable reuse systems. Rigorous focus on ESCPs can reduce the risk of these events by helping detect when they are occurring and implementing emergency response plans.

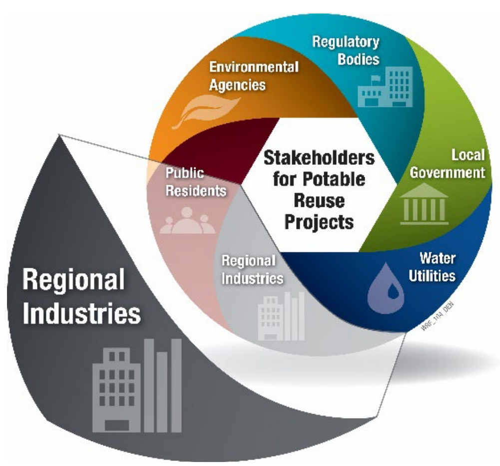

Figure 1-4. Key Stakeholders for Potable Reuse Projects.

Potable reuse systems have a defined connection between the wastewater discharge and the finished water. This brings attention to the dischargers into the wastewater collection system, notably, the industrial dischargers that have not conventionally been considered a key stakeholder in the drinking water system. Part of the focus of this project is to highlight that industries are critical to the success of potable reuse systems and need to be included in discussions early in the planning of the project and throughout its operation. This is a new paradigm for relationships with industries but is a vital step toward creating robust and sustainable water systems. Figure 1-4 highlights the key stakeholders in potable reuse projects.

1.2.4 Risk of Industrial Contaminants in Potable Reuse

Regulating industries is inherently difficult because many of the contaminants that are discharged do not have well-studied toxicological impacts. Changes in industrial processes occur frequently and result in the introduction of new contaminants, leaving regulations to lag behind. As such, there is a need to continuously assess and understand the types of contaminants that are used by different categories of industries and their impact on potable reuse.

This project focuses on the industrial contaminants that have known toxicology for effective screening and prioritization. However, it is noted that there is a research gap by leaving out the contaminants without known toxicology. This is an area identified for future research as the scientific community evaluates more and newer industrial contaminants.

When evaluating the risk of industrial contaminants to potable reuse systems, the following questions should be considered:

1. What groups of contaminants present a human health risk to potable reuse systems?
2. Are those contaminants present in this potable reuse system?
3. Which industries commonly discharge these contaminants and what are the typical flow and loading patterns?
4. How can an ESCP be implemented to effectively mitigate the risk of industrial contamination?

1.2.5 Current State of Knowledge

Designated sections or chapters on source control for potable reuse have been included in many recent frameworks, guidelines, and compendiums on potable reuse (WERF 2011; Tchobanoglous et al. 2015; Debroux et al. 2021b; CA SWRCCB 2019; Rimer and DeCarolis 2017; NWRI 2020; TWDB 2015; Crook et al. 2016; EPA 2017; CWB 2018; Mosher and Vartanian 2018; CWB 2016; NRC 2012; Waller et al. 2018; Mosher et al. 2016; WSAA 2012; many of which are represented on Figure 1-5). These documents typically describe the importance of source control for potable reuse and several include specific recommendations for the various elements of source control programs, notably the Framework for Direct Potable Reuse (Tchobanoglous et al. 2015) and the Australian Sewage Quality Management Guidelines (WSAA 2012).

The goal of this project was to build on the already published information while adding in the research specific to industrial contaminants. While the above-mentioned documents establish the need for ESCPs, most do not go into detail on industrial contaminants and the risk of specific industries. This gap in the current state of knowledge identifies the need and value of this project.

Figure 1-5. Existing Source Control Publications.

CHAPTER 2

Review of Industrial Contaminant Impacts on Potable Reuse Operation and Water Quality

2.1 Introduction

Many industries discharge effluent containing various contaminants to the municipal sewer. Oil and gas extraction sites discharge bromide and iodide (Hladik et al. 2014). Hospitals and pharmaceutical manufacturers release pharmaceuticals (Oliveira et al. 2015; Phillips et al. 2010). Landfills and electroplating facilities emit per- and polyfluoroalkyl substances (PFAS) (Masoner et al. 2020; EGLE 2020). Some of these contaminants may pass through municipal WWTPs and pose various human health or ecological risks such as disinfection byproduct formation (Hladik et al. 2014), increasing antibiotic resistance (Gao et al. 2012), or carcinogenicity (Barry et al. 2013).

The sources, properties, and fate of these industrial contaminants merit renewed scrutiny in the context of potable reuse, which is increasingly implemented to provide resilience to existing water supply portfolios. There is a need for robust contaminant management for potable reuse projects to mitigate the risk of adverse health impacts, such as the use of multiple treatment barriers, an engineered storage buffer, and vigilant monitoring for reliable contaminant removal (Thompson and Dickenson 2020; Pecson et al. 2015). Enhanced source control (i.e., a renewed focus on industrial contaminants released to collection systems motivated by potable reuse) is another preventive barrier to control contaminant risk in potable reuse.

Existing regulations on industrial emissions to municipal sewers have historically focused on the impact of WWTP discharge to surface waters. Thus, limits are primarily based on aquatic ecosystem health, WWTP worker safety, or the physical integrity of sewers and WWTPs. Current limits were not set with potable reuse in mind; thus, attention is needed to provide useful protection to AWTPs and potable reuse consumers. Fortunately, the U.S. NPP includes an objective to improve opportunities to recycle wastewater and gives states and utilities the authority to establish local limits (EPA 2020a). Thus, enhanced source control for potable reuse is consistent with existing regulations and utilities are empowered to use the NPP framework to support the potable reuse system. For example, Los Angeles County Sanitation Districts (LACSD) implemented enhanced source control on oil and gas extraction to reduce boron, and Hampton Roads Sanitation District (HRSD) implemented enhanced source control on a landfill to reduce bromide at reuse facilities (McDonald et al. 2019).

To implement enhanced source control effectively, utilities must know which industrial contaminants occur in wastewater effluent at hazardous concentrations. They must know which of these contaminants are capable of interfering with or passing through the AWTP (along with the upstream WWTP, downstream drinking water treatment facility, or natural barriers, if applicable) at sufficient concentrations of concern. For hazardous contaminants that have been monitored for and detected, utilities should know which industries in their service area are likely sources. Considering the tens of thousands of chemicals registered for use in industry, and the hundreds of industrial contaminants detected in wastewater effluent, robust enhanced source control requires a substantial scientific and engineering knowledge base. Furthermore, in many cases, the industrial purpose of a contaminant may be proprietary or obscure, and its removal by wastewater and water treatment processes may be unknown. This is particularly challenging because industries are continuously inventing and proliferating new chemicals. Thus, continued research is needed to improve this knowledge base for enhanced source control.

In this review, data has been compiled on the toxicity, uses, sources, properties, and removal of industrial contaminants (Appendix A). The scope of this review focused on contaminants with guidelines or regulations in conventional drinking water or reuse and specifically on industrial contaminants, as opposed to contaminants that would enter sewers primarily from residential wastewater or smaller commercial businesses.

The contaminants considered in this review included pharmaceuticals, PFAS, solvents, chemical synthesis precursors, metals, pesticides, nitrogen species, and others. Contaminants were also included with important treatment interference impacts documented in the scientific literature. Contaminants were grouped based on applications and discussed in terms of their likely sources and potential to pass through or interfere with reuse processes. Toxicity, properties, and uses were compiled from online databases (e.g., PubChem, ChemAxon).

Contaminant removals were classified semi-quantitatively based on data in the peer-reviewed literature or technical reports. Where experimental data were not available, removals were predicted based on chemical properties and established heuristics (Dickenson et al. 2009; Bellona et al. 2004; Thompson and Dickenson 2020). This provides a high-level screening of the contaminants, though it is acknowledged that many of the removals included in this review are conservative and site-specific removal data should be used where available. Pass-through hazards were assessed considering reuse treatment trains as whole systems including both the most common [microfiltration (MF), RO and ultraviolet hydrogen peroxide advanced oxidation (UV/H_2O_2)] and the primary alternative [ozonation, biofiltration, granular activated carbon (GAC), and ultraviolet (UV) disinfection]. Industries were categorized as defined in current industrial pretreatment regulations (EPA 2021c) (Table 2-1). Data were organized in a searchable Microsoft Excel spreadsheet provided as a webtool (Appendix A).

Table 2-1. List of 59 USEPA National Pretreatment Program Categories.

Airport Deicing	Ferroalloy Manufacturing	Organic Chemicals, Plastics and Synthetic Fibers (OCPSF)
Aluminum Forming	Fertilizer Manufacturing	Paint Formulating
Asbestos Manufacturing	Glass Manufacturing	Paving and Roofing Materials (Tars and Asphalt)
Battery Manufacturing	Grain Mills	Pesticide Chemicals
Canned and Preserved Fruits and Vegetable Processing	Gum and Wood Chemicals Manufacturing	Petroleum Refining
Canned and Preserved Seafood (Seafood Processing)	Hospitals	Pharmaceutical Manufacturing
Carbon Black Manufacturing	Ink Formulating	Phosphate Manufacturing
Cement Manufacturing	Inorganic Chemicals Manufacturing	Photographic Processing
Centralized Waste Treatment	Iron and Steel Manufacturing	Plastics Molding and Forming
Coal Mining	Landfills	Porcelain Enameling
Coil Coating	Leather Tanning and Finishing	Pulp, Paper, and Paperboard
Concentrated Animal Feeding Operations (CAFO)	Meat and Poultry Products	Rubber Manufacturing
Concentrated Aquatic Animal Production (Aquaculture)	Metal Finishing	Soap and Detergent Manufacturing
Construction and Development	Metal Molding and Casting (Foundries)	Steam Electric Power Generating
Copper Forming	Metal Products and Machinery	Sugar Processing
Dairy Products Processing	Mineral Mining and Processing	Textile Mills
Dental Office	Nonferrous Metals Forming and Metal Powders	Timber Products Processing
Electrical and Electronic Components	Nonferrous Metals Manufacturing	Transportation Equipment Cleaning
Electroplating	Oil and Gas Extraction	Waste Combustors
Explosives Manufacturing	Ore Mining and Dressing (Hard Rock Mining)	

2.2 List of Contaminants Included in the Analysis

Contaminants reviewed were sourced from the following lists and are shown in Table 2-3:

- USEPA Primary Maximum Contaminant Levels (MCLs)
- USEPA Secondary MCLs
- USEPA Health Advisory Levels (HALs)
- USEPA Contaminant Candidate List Four (CCL4)
- USEPA Unregulated Contaminant Monitoring Rule Five (UCMR5)
- California Notification Levels (NLs)
- California Toxics Rule
- United Kingdom Drinking Water Guidelines (DWGs)
- Australian DWG
- Canadian DWGs
- Australia reuse guidelines
- World Health Organization DWGs
- Health-based indicators from WRF Report #4494 (USEPA 2020b; 2020c; Rauch-Williams et al. 2018; USEPA 2018; 2019; SWRCB 2020; USEPA 2012; Australian Government 2018; Health Canada 2019; WHO 2017; UKDWI 2016)
- Twenty-one PFAS were included based on their detection in United States wastewater effluent (Houtz et al. 2016; Quiñones and Snyder 2009; Houtz et al. 2018; Dixon-Anderson and Lohmann 2018; Boulanger et al. 2005; Elmoznino et al. 2018; Appleman et al. 2014;

Sinclair and Kannan 2006). Certain PFAS, even though they have been phased out, were still included in the scope due to their high emission from landfills (Masoner et al. 2020a).

- Twenty-one pharmaceuticals were included with aquatic ecosystem risk quotients greater than one in Oliveira et al. (2015).
- Many pesticides have MCLs or DWGs and are not fully banned but their production in industry is rare because they are highly restricted, economically obsolete, or serve niche purposes; thus, pesticides were only included if they have USEPA Primary MCLs or were among the top 25 most used pesticides in agriculture in the United States in 2012 (Atwood and Paisley-Jones 2017).
- Bromide, acetone, methadone, isopropyl alcohol, and iodinated contrast media (ICMs) were included based on their interference potential (Hanigan et al. 2015; Wang et al. 2016; Hladik et al. 2014; Dadakis and Dunivin 2013; Debroux et al. 2021a).
- The industrial corrosion inhibitor benzotriazole was also included due to its prevalent detection and high concentrations in wastewater effluent (Schimmoller et al. 2020; Loos et al. 2013).

Many contaminants were omitted from this research to focus the scope of the project. These contaminants are shown in Appendix A with the primary reason for omission. Disinfection byproducts and drinking water disinfectants were not included because these are more likely to originate within the water purification facility than from an industrial source. An exception was made for *N*-nitrosodimethylamine (NDMA) as it has been detected in wastewater primary, secondary, and tertiary effluents at levels indicating local industrial sources of NDMA or unidentified NDMA precursors (Gerrity et al. 2015; Anderson et al. 2010; Chuang et al. 2019). Polyaromatic hydrocarbons or dioxins were only included if they have industrial applications rather than existing solely as combustion byproducts. Pathogens and chemicals with predominantly biological origin (e.g., cyanotoxins, cholesterol, metabolites) were beyond the scope of this review as they are unlikely to be mitigated through an ESCP. Chemicals that are banned or phased out in the United States (e.g., ozone-depleting chlorofluorocarbon refrigerants, chemical warfare agents, many former pesticides) were also out of scope because their industrial emission is currently unlikely.

The reviewed contaminants were categorized into families and sub-families as shown in Table 2-2. "Industrial Precursors" as used in the context of chemical families refers to organic chemicals used as initial or intermediate building blocks to make other chemicals (e.g., monomers for plastics). These are not to be confused with disinfection byproduct (DBP) precursors and perfluoroalkyl acid (PFAA) precursors, both of which are discussed in this review as important interference types. DBP precursors are compounds that may transform into known DBPs during disinfection. PFAA precursors are polyfluoroalkyl substances that may transform into known PFAAs in wastewater treatment, water treatment, the environment, or the human body (Houtz and Sedlak 2012). Short-chain perfluoroalkyl substances were defined as perfluorocarboxylic acids (PFCAs) with seven or fewer carbons and perfluorosulfonic acids (PFSAs) with five or fewer carbons (Buck et al. 2011; Brendel et al. 2018).

Table 2-2. Chemical Families and Sub-Families.

Chemical Category	n	Sub-Family	n
Solvents & Industrial Precursors	104[a]	Neutral	61[a]
		Polar	41
		Charged	2
PFAS	21	Long-chain Perfluoroalkyl Substances	6
		Short-chain Perfluoroalkyl Substances	5
		Polyfluoroalkyl Substances	10
Pharmaceuticals	37	ICMs	5
		Antibiotics	4
		Hormones	7
		Other Pharmaceuticals	21
Nitrogen	3	n/a	n/a
Metals	18	n/a	n/a
Pesticides	29[a]	n/a	n/a
Other Organics	31	n/a	n/a
Other Inorganics	20	n/a	n/a

[a] One compound, 1,3-dichloropropene, was classified as both a Pesticide and a Neutral Industrial Precursor

Table 2-3. List of 262 Contaminants Included in the Review.

Other names, regulatory lists, properties, and removals for each contaminant are listed in Appendix A.

Contaminants Included in Review				
1,1,1,2-Tetrachloroethane	Acetaldehyde	Copper	Iron	Perfluorodecanoic Acid
1,1,2,2-Tetrachloroethane	Acetamide	Coumarin	Isophorone	Perfluoroheptane sulfonic Acid
1,1,2-Trichloroethane	Acetaminophen	Cumene Hydroperoxide	Isopropyl alcohol	Perfluoroheptanoic Acid
1,1-Dichloroethane	Acetochlor	Cyanide	Isopropylbenzene	perfluorohexane Sulfonic Acid
1,1-Dichloroethene	Acetone	Cyclonite	Ketoprofen	Perfluorohexanoic Acid
1,2,3-Trichloropropane	Acrolein	Dalapon	Lanthanum	Perfluorononanoic Acid
1,2,4-Trichlorobenzene	Acrylonitrile	Deethylatrazine	Lead	Perfluorooctane Sulfonic Acid
1,2,4-Trimethylbenzene	Alachlor	Di(2-Ethylhexyl) Adipate	Lidocaine	Perfluorooctanoic Acid
1,2-Dibromoethane	Alprazolam	Di(2-Ethylhexyl)Phthalate	Magnesium	Perfluoropentanoic Acid
1,2-Dichlorobenzene	Aluminum	Diatrizoic Acid	Mancozeb	Phenanthrene
1,2-Dichloroethane	Ammonia	Diazepam	Manganese	Phenol
1,2-Dichloropropane	Aniline	Dicamba	Mercury	Phthalic anhydride
1,3,5-Trichlorobenzene	Anthracene	Dichloromethane	Mestranol	Picloram
1,3,5-Trimethylbenzene	Antimony	Diclofenac	Metam	Primidone
1,3-Butadiene	Arsenic	Diethyl Phthalate	Methadone	Propanil
1,3-Dichloropropene	Asbestos	Dimethyl Methylphosphonate	Methanol	Propanolol
1,3-Dinitrobenzene	Atrazine	Dimethyl Phthalate	Methyl Chloride	Propylenedinitrilotetraacetic Acid
1,4-Dichlorobenzene	Barium	Di-*n*-Butyl Phthalate	Methyl Ethyl Ketone	Pyrene
1,4-Dioxane	Benzene	Di-*n*-Octyl Phthalate	Methyl Isobutyl Ketone	Quinoline
1,4-Dithiane	Benzotriazole	Diquat	Methyl *tert*-Butyl Ether	Radium
10:2 Fluorotelomer Alcohol	Benzo[a]pyrene	Edetic Acid	Metolachlor	*sec*-Butylbenzene

(Continued)

Table 2-3. Continued.

Contaminants Included in Review				
17-Alpha-Ethinyl Estradiol	Benzyl Chloride	Endothall	Metoprolol	Selenium
1-Butanol	Beryllium	Epichlorohydrin	Molybdenum	Silica
2,4,6-Trichlorophenol	Bis(2-Chloro-1-Methylethyl) Ether	Equilenin	Morphine	Silver
2,4,6-Trinitrotoluene	Bis(2-Chloroethoxy)Methane	Equilin	Napthalene	Simazine
2,4-Dichlorophenol	Bis(2-Chloroethyl)Ether	Erythromycin	*n*-Butylbenzene	Strontium
2,4-Dichlorophenoxyacetic Acid	Bis(2-Chloroisopropyl)Ether	Estriol	*N*-Ethylperfluorooctane Sulfonamide Acetic Acid	Styrene
2,4-Dimethylphenol	Bisphenol A	Estrone	Nicarbazin	Sulfamethoxazole
2,4-Dinitrophenol	Boron	Ethephon	Nickel	Sulfate
2,4-Dinitrotoluene	Bromide	Ethylbenzene	Nitrate	Sulfide
2,6-Dinitrotoluene	Bromobenzene	Ethylene Glycol	Nitrilotriacetic Acid	Tellurium
2,6-Di-*tert*-Butyl-1,4-benzoquinone	Bromochloromethane	Ethylene Oxide	Nitrite	*tert*-Butylbenzene
2-Chloroethylvinyl Ether	Butylated Hydroxyanisole	Ethylene Thiourea	Nitrobenzene	Tertiary Butyl Alcohol
2-Chlorophenol	Butylated Hydroxytoluene	Fipronil	Nitroglycerine	Tetrachloroethene
2-Methoxyethanol	Butylbenzyl Phthalate	Fluoride	Nitroguanidine	Thallium
2-Nitrophenol	Cadmium	Fluoxetine	*N*-Methylperfluorooctane Sulfonamidoacetic Acid	Tin
2-Propen-1-ol	Caffeine	Furosemide	*N*-Nitrosodimethylamine	Toltrazuril
3,3'-Dichlorobenzidine	Calcium	Gabapentin	*N*-Nitrosodiphenylamine	Toluene
4,4'-Methylenedianiline	Carbamazepine	Gemfibrozil	*N*-Nitrosomorpholine	Toluene Diisocyanate
4-Cumylphenol	Carbofuran	Germanium	Norethindrone	*trans*-1,2-Dichloroethylene
4-Nitrophenol	Carbon Disulfide	Glufosinate	*n*-Propylbenzene	Trichloroethene
4-Nonylphenol	Carbon Tetrachloride	Glyphosate	*o*-Chlorotoluene	Triethylamine
5:3 Fluorotelomer Carboxylic Acid	Chloride	Hexachlorobutadiene	Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine	Trifluralin
5-Methyl-1H-Benzotriazole	Chlorobenzene	Hexachloro-cyclopentadiene	*o*-Toluidine	Trimethoprim
6:2 Fluorotelomer Alcohol	Chloroethane	Hexachloroethane	Oxamyl	Tris(1,3-Dichloro-2-Propyl) Phosphate
6:2 Fluorotelomer Sulfonic Acid	Chlorophene	Hydrazine	Oxirane, methyl-	Tris(2-Chloroethyl) Phosphate
8:2 Fluorotelomer Alcohol	Chlorothalonil	Ibuprofen	Paraquat	Uranium
8:2 Fluorotelomer Carboxylic Acid	Chlorpyrifos	Iodide	*p*-Chlorotoluene	Urethane
8:2 Fluorotelomer Sulfonic Acid	Chromium	Iohexol	Pendimethalin	Vanadium
8:2 Fluorotelomer Unsaturated Carboxylic Acid	cis-1,2-Dichloroethylene	Iomeprol	Pentachlorophenol	Vinyl Chloride
Acenaphthene	Clarithromycin	Iopamidol	Perfluorobutane Sulfonic Acid	Xylenes
Acenaphthylene	Cobalt	Iopromide	Perfluorobutanoic Acid	Zinc
Acephate	Codeine			

2.3 Advanced Treatment Processes Analyzed

Contaminants were first categorized based on their removal by the following processes: municipal WWTP, conventional drinking water treatment plant (DWTP) (i.e., coagulation, flocculation, sedimentation, and filtration), ozonation, biofiltration, GAC, RO, UV disinfection, high-dose direct UV photolysis, and UV/H_2O_2. Semiquantitative removal categories were Excellent (greater than or equal to [≥] 90%), Good (60 to 89%), Fair (20 to 59%), Poor (0 to 19%), and Negative (less than [<] 0%). Negative removal included, for example, generation of PFAAs from polyfluorinated precursors. Because GAC percent removal is time dependent, GAC removal categories were instead defined by bed volumes until 10% breakthrough as shown in Table 2-4.

Literature was reviewed to compile removal data for each contaminant through each type of process (Appendix A). Full- or pilot-scale data were used where available, but bench-scale data were included otherwise. Where removal data were not available, known chemical properties were used to predict the semiquantitative removal category. Removal data based on ambient (i.e., un-spiked) concentrations in real municipal wastewater effluent was compiled unless otherwise noted. Exceptions to these preferred constraints were noted in a Notes column (Appendix A). Furthermore, removal data from contextually appropriate matrices, i.e., wastewater effluent treated by processes found upstream in typical reuse trains (e.g., RO permeate for UV/H_2O_2) were used where available. Removal for metals and other inorganics by GAC, biofiltration, UV, ozonation, and UV/H_2O_2 was assumed Poor in the absence of data to the contrary.

Table 2-4. Semiquantitative Removal Category Thresholds.

Semiquantitative Category	GAC		Other Processes
	Thousand Bed Volumes Until 10% Breakthrough	Months Until 10% Breakthrough, 20 min EBCT	Percent Removal
Excellent	>20	>9.3	≥90%
Good	10-20	4.6–9.3	60–89%
Fair	5-10	2.3–4.6	20–59%
Poor	<5	<2.3	0–19%
Negative			<0%

WWTP data were included for conventional activated sludge (CAS) or biological nutrient removal. Data were not included for trickling biofilters, membrane bioreactors, or rotating biological contactors. Data were not included for CAS treating 100% industrial wastewater, because industrial wastewaters are not expected to be representative of the majority residential municipal wastewaters used for potable reuse. Furthermore, 100% industrial wastewaters would generally have much higher concentrations of the investigated contaminant than in typical municipal wastewater. These higher concentrations would likely acclimatize the microbial community, leading to higher removals than could be expected at a municipal WWTP during normal conditions or a transient concentration spike.

Coagulation and flocculation were assumed to be the primary chemical removal mechanisms within conventional DWTPs, as opposed to sedimentation or filtration. Coagulation data were included for alum, ferric chloride, polyaluminum chloride, and polymer coagulant aids at typical drinking water doses (i.e., tens of mg/L) (Hill et al. 2018). If experimental data were not available, coagulation removal was assumed Poor unless pH-adjusted octanol-water partition coefficient (logD) was greater than 5 (Snyder et al. 2007). Due to limited sample size within the high logD range in the cited reference, Fair, Good, or Excellent coagulation removal were only differentiated based on experimental data.

Ozonation data were included for typical ozone doses applied in reuse practice: O_3:TOC ratios of 0.6-1.0 mg/mg or ozone exposures of 4-11 mg*min/L (Dickenson et al. 2009). In the absence of full- or pilot-scale wastewater ozonation data, removals were estimated based on chemical structure. Contaminants with second order ozone reaction rates (k_{O3}) greater than 1 $M^{-1}s^{-1}$ typically have Excellent removal in wastewater effluent (Dickenson et al. 2009). Inorganics and metals were assumed to pass through ozonation, though problematic changes in oxidation state were sometimes noted as interference (e.g., bromide oxidation to bromate).

Biofiltration data were included for submerged, aerobic, downflow columns at typical empty bed contact times (i.e., 10 to 30 minutes) with sand, anthracite, or exhausted GAC. Like WWTP removal, biofiltration data were not included for 100% industrial wastewaters because differences from municipal wastewater quality (e.g., co-substrates) would impact biofiltration performance (Hu et al. 1998).

GAC data were limited to column-mode data due to the inherent difficulty in extrapolating breakthrough in real waters from batch-mode tests. Typical GAC empty bed contact times were assumed to be between 10 and 30 minutes. GAC removal data were not included if the GAC age or bed volumes were not stated. When sufficient column-mode data were not available, expected removal was predicted based on logD with the thresholds shown in Table 2-5. However, these thresholds were based on a data set without pre-ozonation (Thompson and Dickenson 2020). So, actual removals may be somewhat higher, because pre-ozonation can increase GAC removal, likely by decreasing competition for adsorption sites (Sun et al. 2018). Positively charged compounds are better removed than would be predicted based on logD, but the extent of this impact varies (Thompson and Dickenson 2020). GAC percentage removal is effectively independent of initial concentration over a range of about an order of magnitude (e.g., 10 nanograms per liter [ng/L] vs. 100 ng/L) (Matsui et al. 2002b), but may vary between initial concentrations that differ by multiple orders of magnitude (Shimabuku et al. 2017). Thus, GAC studies with industrial wastewater or spiked chemicals in the µg/L or mg/L range are likely not representative of GAC performance in the potable reuse context.

GAC effective adsorption capacity is much lower in wastewater effluent than in surface water with lower dissolved organic carbon (DOC) (Inyang and Dickenson 2017). Furthermore, the extent of background organic matter competition depends on the molecular weight of both the organic matter and the contaminant of interest (Matsui et al. 2002a). Sorption competitive effects also depend on the adsorbability and functional groups of competing specific adsorbates (Shimabuku et al. 2017). Thus, GAC studies in other water types may not be representative of GAC performance in potable reuse even if the DOC concentration is similar.

Table 2-5. Expected Removal Categories Based on Chemical Properties.

Process	GAC[a]	UV Disinfection (276 mJ/cm2)	High-Dose UV Photolysis (1,000 mJ/cm2)	UV/H_2O_2
Property	logD	ε×ϕ (mol/cm*E)	ε×ϕ (mol/cm*E)	$k_{OH\cdot}$ (10^9 1/M/s)
Excellent		>1700	>700	>5
Good	>2	400–1700	100–700	2–5
Fair	0.5–2	70–400	10–100	0.6–2
Poor	<0.5	<70	<10	<0.6

[a] For negative or neutral compounds if column-mode experimental data not available.

Note: mJ/cm2 = millijoule per square centimeter

Direct UV photolysis was considered at two fluence doses: 276 millijoule per square centimeter (mJ/cm^2) and 1,000 mJ/cm^2. The former represents the high end of doses applied with the primary goal of credited pathogen disinfection (i.e., 6 log reduction in virus) (Adams 2016). The latter represents doses applied in UV advanced oxidation applications (Glover et al. 2019; Marron et al. 2019; Glover et al. 2018). Thus, it is economically plausible that UV doses around 1,000 mJ/cm^2 could be applied in scenarios in which the primary goal is removal of UV-labile compounds such as NDMA or N-nitrosomorpholine (NMOR) (Glover et al. 2019; Thompson and Dickenson 2020). In both cases, the UV wavelength was 254 nanometer, typical of low-pressure lamps used for UV disinfection and advanced oxidation (Marron et al. 2019; Amoueyan et al. 2017). When available, UV photolysis removal was estimated based on the product of molar absorption coefficient (ε) and quantum yield (ϕ) as was done in Thompson and Dickenson (2020). The resulting value, shown as ε×ϕ in Table 2-5, were identified and thresholds were set by correlating ε×ϕ against interpolated removal by a UV dose of 276 or 1,000 mJ/cm^2 using the compounds and data in Yu et al. (2015), Glover et al. (2019), and Sharpless and Linden (2003). UV photolysis was assumed Poor for metals and inorganics. UV photolysis removal was assumed Poor if UV/H_2O_2 removal was Poor.

For UV/H_2O_2, constraints for UV dose and wavelength were the same as for high-dose direct UV photolysis described above. Typical H_2O_2 doses were considered 3-10 mg/L (Marron et al. 2019; Glover et al. 2018). UV/H_2O_2 removal was assumed at least as high as high-dose UV removal. For UV recalcitrant compounds, UV/H_2O_2 removal was predicted based on second order hydroxyl radical reaction rate ($k_{OH\cdot}$) and Figure 4 of Marron et al. (2019), assuming <0.5 mg/L TOC in RO permeate.

Organic compounds with positive or negative charge or molecular weight greater than 200 grams per mole (g/mol) were assumed to have over 90% removal by RO (Bellona et al. 2004). Where possible, RO removal of low molecular weight (<200 g/mol), neutral compounds without available experimental data were estimated using the quantitative structure-activity relationship (QSAR) developed by Kibler et al. (2020). However, the applicability of this QSAR was limited because it did not include sulfur-containing, phosphorus-containing, nitrile, ether, phenolic, alkene alcohols, nitro aromatic, or heterocyclic compounds.

2.4 Advanced Treatment Trains

Overall removals were calculated for three typical combinations of treatments processes:

- Train A is a membrane-based reuse train consisting of microfiltration/ultrafiltration, RO, and UV/H_2O_2 advanced oxidation, though microfiltration/ultrafiltration was not analyzed in this review due to low chemical removal. This treatment train has been implemented at full-scale at multiple locations in California (Marron et al. 2019).
- Train B is a carbon-based (non-membrane) reuse scheme consisting of ozonation, biofiltration, GAC adsorption, and UV disinfection at 276 mJ/cm^2. These types of reuse trains have been pilot tested as a lower cost alternative, particularly in areas where RO concentrate discharge to ocean is not available (Glover et al. 2018; Glover et al. 2019). Train B has been implemented in Virginia and piloted in several locations across the country (Gonzalez et al. 2021; Glover et al. 2018). Though it is acknowledged that there are many different variations of carbon-based advanced treatment, this particular scheme was selected for use in this project.
- Train C is the membrane-based reuse train (Train A) that also includes ozonation and biological activated carbon (BAC) (Figure 2-1). Train C would be the required system to meet draft criteria for DPR in California (CWB 2021a).

Preexisting conventional WWTPs and DWTPs were assumed upstream and downstream of the advanced treatment trains and were included in total removal calculations. Utilities considering other combinations of the same processes could estimate their overall removal using the information provided in Appendix A.

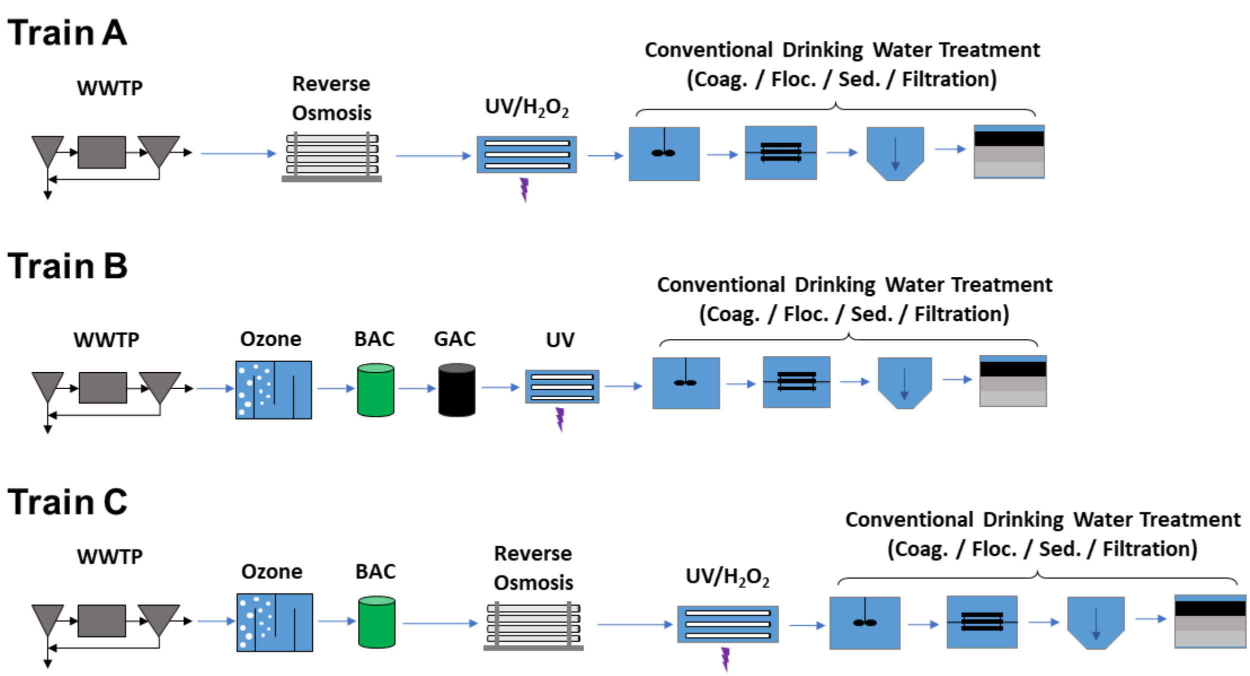

Figure 2-1. Reuse Treatment Trains Assessed.

2.5 Industrial Contaminant Screening Scores

An Industrial Contaminant Screening Score (ICSS) that accounts for removal and toxicity was calculated for each contaminant for all three advanced treatment trains. ICSS is not a metric of risk because it does not incorporate concentration or exposure. Rather, it is a tool to prioritize contaminants for collecting occurrence data. This was done so that contaminants with higher toxicities or less removal would be prioritized for monitoring over those with lower toxicities or higher removal. Furthermore, contaminants with predominantly industrial origin are anticipated to have highly site-specific and temporally variable concentrations. Chapter 5 discusses how to incorporate the ICSS into a risk assessment once the site-specific occurrence data for prioritized contaminants are known.

ICSS was calculated by dividing the fraction remaining by the lower of two toxicity metrics: oral chronic reference dose (RfD) (milligrams per kilogram per day [mg/kg/day]) or risk-specific dose (RSD) (mg/kg/day). That is:

$$\boldsymbol{ICSS} = (\mathbf{1} - \boldsymbol{R_{overall}})/\mathbf{min}\,\{\boldsymbol{RfD}, \boldsymbol{RSD}\}$$ **Equation 2-1**

RfDs are calculated by dividing the No Observed Adverse Effect Level by safety factors for interspecies differences, intraspecies sensitivity, and other uncertainty factors (Davis and Masten 2009). RfDs generally pertain to noncancer toxicity endpoints. RSD based on a one-in-ten-thousand risk (10^{-4} risk) was calculated from oral cancer slope factor (CSF) as:

$$RSD = 10^{-4}/CSF$$ **Equation 2-2**

One-in-ten-thousand is the cancer risk level used by the USEPA when deciding whether cancer or noncancer risk levels provide more meaningful scenario-specific risk reduction (EPA 2018). RfDs and CSFs were obtained from the Risk Assessment Information System database or the EPA list of health advisories (Galloway et al. 2020; EPA 2018). ICSS was calculated directly from toxicity metrics rather than MCLs or guidelines because these often take into account economic considerations (i.e., monitoring and treatment economic feasibility for small utilities) that would not be relevant for this research. Nonetheless, USEPA primary MCLs and MCL goals are included in Appendix A to help utilities weigh contaminants by these values. Sub-chronic, short-term, and acute oral reference doses were also included in Appendix A in case any utilities might prefer to compare based on these metrics for industrial contaminants with transient spikes in concentration. Either CSF or RfD was available for 169 out of the 262 reviewed contaminants (65%). Notably missing were CSF or RfD for PFAS other than perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorobutanoic acid (PFBA), and perfluorobutane sulfonic acid (PFBS). As such, only those four PFAS were included in the ICSS evaluation.

The overall removal ($R_{overall}$) for each train was calculated as shown in Equation 2-3, where R_1, R_2, etc. are the removals for each process in the train.

$$R_{overall} = 1 - (1 - R_1)(1 - R_2) \dots (1 - R_n)$$ **Equation 2-3**

As discussed above, the background concentration was not a factor in the ICSS because concentrations of contaminants originating from industrial point-sources to sewers are site-specific and often intermittent. Chapter 5 discusses how a utility can take site-specific data and apply it to the ICSS to perform a contaminant risk assessment. A contaminant could have a high ICSS yet present a low risk due to low influent concentration. Alternatively, a contaminant with a low ICSS could present a high risk if there are abnormally high influent concentrations. It is important to keep this concept in mind when reviewing the ICSS values presented below.

The removals for each process were approximated by assuming the midpoint of the range of the semiquantitative categories, e.g., 95% removal for Excellent (Table 2-4). As an exception, 0% was assumed for Poor or Negative removal. Contaminants that spanned multiple categories in sampled full-scale sites were given the midpoint of the combined range; for example, a contaminant whose removal was Poor (0 to 20%) to Fair (20 to 60%), would be assigned a midpoint of 30%.

Example removals for PFOA and PFOS in Train B are shown in Equations 2-4 and 2-5. PFOA would have Poor WWTP removal (0%), Poor or even Negative ozonation removal (0%), Poor or Negative biofiltration removal (0%), Poor to Good GAC removal (45%), Poor UV removal (0%), and Poor DWTP removal (0%) (Appleman et al. 2014; Arvaniti et al. 2014; Sundaram and Pagilla 2020; Sun et al. 2018; Glover et al. 2018). So, the Train B overall removal would be:

$$\begin{aligned} R_{PFOA,Train\ B} &= 1-(1-R_{WWTP})(1-R_{O3})(1-R_{BAC})(1-R_{GAC})(1-R_{UV})(1-R_{DWTP}) \\ &= 1-(1-0)(1-0)(1-0)(1-0.45)(1-0)(1-0) = 0.45 \end{aligned}$$

Equation 2-4

In contrast, PFOS would have Fair WWTP removal (40%), Poor ozonation removal (0%), Poor biofiltration removal (0%), Good GAC removal (75%), Poor UV removal (0%), and Poor DWTP removal (0%) (Appleman et al. 2014; Arvaniti et al. 2014; Glover et al. 2018). So, the Train B overall removal would be:

$$\begin{aligned} R_{PFOS,Train\ B} &= 1-(1-R_{WWTP})(1-R_{O3})(1-R_{BAC})(1-R_{GAC})(1-R_{UV})(1-R_{DWTP}) \\ &= 1-(1-0.4)(1-0)(1-0)(1-0.75)(1-0)(1-0) = 0.85 \end{aligned}$$

Equation 2-5

A limitation of this approximation is that it does not differentiate between contaminants that were near the upper or lower thresholds of the semiquantitative removal categories. For example, there would be no differentiation between contaminants with 91% vs. 99% removal by a process, because both would be categorized as Excellent. This is particularly notable for RO, which has at least 99% removal of many highly toxic PFAS and metals (Kucharzyk et al. 2017; Qdais and Moussa 2004; Appleman et al. 2014). Thus, the ICSSs as calculated in this report should be considered approximate and conservative examples, particularly for charged or highly molecular weight compounds such as PFAS in Trains A and C. For risk assessment, these approximate removals should be substituted with site-specific pilot- or demonstration-scale data once available (see Chapter 5).

Toxicity metrics and removal data, or applicable QSARs, for all Train A processes were available to calculate overall Train A ICSSs for 56 of the 262 contaminants evaluated. The contaminants with the top twenty highest known Train A ICSSs are listed in Table 2-6. Among these were several PFAS (PFOA, PFOS, PFBA, and PFBS) and metals (uranium, cobalt, and mercury). While these contaminants would be removed by well over 90% by RO in Train A, their toxicity is such that they would merit monitoring and potentially enhanced source control as a redundant measure to prevent exposure in the unlikely event of RO membrane integrity failure.

NDMA ranked highest for Train A ICSS because it ranked lowest for Train A removal, RfD, and RSD (lower indicating more toxic according to these metrics). NDMA is primarily used as a research chemical and former uses such as rocket fuel have been phased out (National Library of Medicine 2020). On the other hand, high concentration outliers in primary effluent have been documented in recent scientific literature (Gerrity et al. 2015). Concentrations below around 80 ng/L likely originated as a thermal byproduct in food or a DBP from non-industrial precursors (Park et al. 2015; Anderson et al. 2010; Gerrity et al. 2015; Chuang et al. 2019). Considering these facts, if tracing the source of atypically high NDMA concentrations, ESCP staff should consider the possibility that NDMA transformed from other industrial contaminants within the collection system. Industrial sources of NDMA precursors include textile manufacturing, metal finishing, and electronics (Chuang et al. 2019; Gerrity et al. 2015).

NMOR had the fourth highest Train A ICSS. Once assumed to be a DBP, recent research has shown NMOR does not significantly increase in ozonation or chloramination of wastewater samples (Chuang et al. 2019; Glover et al. 2019). NMOR is not used commercially in the USA according to the USEPA (National Library of Medicine 2020), and neither domestic sewage nor the investigated industrial sources could explain the NMOR measured in primary effluent by Chuang et al. (2019). Yet, NMOR is widely detected in wastewater effluent at concentrations over 10 ng/L (Glover et al. 2019). One proposed explanation is the nitrosation of morpholine, a solvent, industrial precursor, and rubber accelerator (National Library of Medicine 2020). NMOR has been measured as a thermal byproduct in food at comparable concentrations to NDMA (Park et al. 2015) but it is not typically detected in human waste (Zeng and Mitch 2015)

Table 2-6. Highest 20 *Train A*[a] ICSS for Well-Studied Contaminants, Assuming Midpoints of Removal Categories.
Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF (mg/kg/day)$^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train A Overall Removal	ICSS (mg/kg/day)$^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	85%	76500
PFOA[b]	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	95% [b]	2500
PFOS[b]	NA	NA	2.0×10^{-5}	2.0×10^{-5}	97%[b]	1500
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99%	503
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	89%	113
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	97%	100
PFBS[b]	NA	NA	3.0×10^{-4}	3.0×10^{-4}	97%[b]	100
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	95%	77
PFBA[b]	NA	NA	1.0×10-3	1.0×10-3	97%[b]	35
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99%	34
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	100%	30
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	99%	30
Cyanide	NA	NA	6.0×10^{-4}	6.0×10^{-4}	98%	27
2,4,6-Trichlorophenol	0.011	9.1×10^{-3}	3.0×10^{-4}	3.0×10^{-4}	99%	25
1,2,4-Trichlorobenzene	0.029	3.4×10^{-3}	1.0×10^{-2}	3.4×10^{-3}	94%	18
Atrazine	0.23	4.3×10^{-4}	2.0×10^{-2}	4.3×10^{-4}	99%	17
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	99%	15
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	95%	10
1,2-Dichloroethane	0.091	1.1×10^{-3}	4.0×10^{-2}	1.1×10^{-3}	99%	8.0
TDCPP	NA	NA	2.0×10^{-2}	2.0×10^{-2}	95%	2.5

[a] WWTP, RO, UV/H_2O_2, DWTP
[b] Overall removal of PFAS is based on a conservative assumption for RO (95% removal) due to the screening process using the midpoint removal. Actual removal is likely much greater as research has indicated complete removal of PFAS through RO (Kucharzyk et al. 2017; Appleman et al. 2014).
Notes: TCEP = tris(2-chloroethyl) phosphate, TDCPP = tris(1,3-dichloro-2-propyl) phosphate

Toxicity metrics and removal data, or applicable QSARs, for all Train B processes were available to calculate overall Train B ICSSs for 43 of the 262 contaminants evaluated. The contaminants with the top twenty highest known Train B ICSSs are listed in Table 2-7. Like in Train A, the highest ranked contaminant was NDMA and many of the other highly ranked contaminants were PFAS (PFOA, PFOS, PFBA, and PFBS) or metals (cobalt, uranium, and chromium). As discussed in Section 2.7, these classes of contaminants are often pass-through hazards for Train B.

Table 2-7. Highest 20 *Train B*[a] ICSS for Well-Studied Contaminants, Assuming *Midpoints* of Removal Categories. *Note that this table identifies contaminants that* are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train B Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	85%	76500
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	45%	27500
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	85%	10050
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	85%	7500
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	40%	2000
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	40%	2000
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	30%	700
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	80%	675
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	96%	600
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	88%	600
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	75%	385
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	85%	300
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	85%	150
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	40%	30
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	95%	10
Selenium	NA	NA	5.0×10^{-3}	5.0×10^{-3}	97%	7.0
Fluoride	NA	NA	4.0×10^{-2}	4.0×10^{-2}	80%	5.1
Iodide	NA	NA	1.0×10^{-2}	1.0×10^{-2}	95%	5.0
Copper	NA	NA	4.0×10^{-2}	4.0×10^{-2}	85%	3.8
Carbon Tetrachloride	0.07	1.4×10^{-3}	4.0×10^{-3}	1.4×10^{-3}	100%	3.1

[a] WWTP, Ozonation, Biofiltration, GAC, UV disinfection, DWTP

Toxicity metrics and removal data, or applicable QSARs, for all Train C processes were available to calculate overall Train C ICSSs for 42 of the 262 contaminants evaluated. The contaminants with the top twenty highest known Train C ICSSs are listed in Table 2-8. Similar to Trains A and B, the highest ranked contaminant was NDMA and many of the other highly ranked contaminants were PFAS (PFOA, PFOS, PFBA, and PFBS) or metals (cobalt, uranium, and cobalt).

Table 2-8. Highest 20 *Train C*[a] ICSS for Well-Studied Contaminants, Assuming *Midpoints* of Removal Categories.
Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train C Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	91%	45900
PFOA[b]	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	95%[b]	2500
PFOS[b]	NA	NA	2.0×10^{-5}	2.0×10^{-5}	97%[b]	1500
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99%	503
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	97%	100
PFBS[b]	NA	NA	3.0×10^{-4}	3.0×10^{-4}	97%[b]	100
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	95%	77
PFBA[b]	NA	NA	1.0×10^{-3}	1.0×10^{-3}	97%[b]	35
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99%	34
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	100%	30
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	99%	30
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	98%	17
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	99%	15
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	95%	10
TDCPP	NA	NA	2.0×10^{-2}	2.0×10^{-2}	95%	2.5
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	97%	1.5
Atrazine	0.23	4.3×10^{-4}	2.0×10^{-2}	4.3×10^{-4}	100%	0.86
Carbon Tetrachloride	0.07	1.4×10^{-3}	4.0×10^{-3}	1.4×10^{-3}	100%	0.63
Selenium	NA	NA	5.0×10^{-3}	5.0×10^{-3}	100%	0.35
Fluoride	NA	NA	4.0×10^{-2}	4.0×10^{-2}	99%	0.25

[a] WWTP, Ozonation, Biofiltration, RO, UV/H_2O_2, DWTP.
[b] Overall removal of PFAS is based on a conservative assumption for RO (95% removal) due to the screening process using the midpoint removal. Actual removal is likely much greater as research has indicated complete removal of PFAS through RO (Kucharzyk et al. 2017; Appleman et al. 2014).

As a sensitivity analysis, ICSS were also ranked assuming the low or high end of the semiquantitative removal category, though with Poor still assumed 0% and Excellent having a maximum of 99% (Tables 2-9 through 2-14). For Train A, regardless of the assumptions, the highest ranking five contaminants were NDMA, PFOA, PFOS, NMOR, and 1,4-dioxane, though not necessarily in the same order (Tables 2-6, 2-9, and 2-10). Eighteen of the top highest ranking 20 contaminants were the same for Train A under all three sets of assumptions. For Train B, the six highest ranked contaminants were the same and in the same order regardless of assumptions (Tables 2-7, 2-11, and 2-12). Seventeen of the 20 highest ranked contaminants for Train B were the same regardless of assumptions though not all in the same order. For Train C, the highest four were the same and in the same order under all three sets of assumptions, and 18 of the highest 20 were the same though not necessarily in the same order (Tables 2-8, 2-13, and 2-14). Thus, while the ICSS presented in this report could be considered approximate and conservative, the resulting rankings were nonetheless not sensitive to the underlying assumptions.

Table 2-9. Highest 20 *Train A*[a] ICSS for Well-Studied Contaminants, Assuming *Lower-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train A Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	$2.0×10^{-6}$	$8.0×10^{-6}$	$2.0×10^{-6}$	68%	163200
PFOA	0.07	$1.4×10^{-3}$	$2.0×10^{-5}$	$2.0×10^{-5}$	90%	5000
PFOS	NA	NA	$2.0×10^{-5}$	$2.0×10^{-5}$	92%	4000
NMOR	6.7	$1.5×10^{-5}$	NA	$1.5×10^{-5}$	97%	2144
1,4-Dioxane	0.1	$1.0×10^{-3}$	$3.0×10^{-2}$	$1.0×10^{-3}$	68%	320
Cobalt	NA	NA	$3.0×10^{-4}$	$3.0×10^{-4}$	92%	267
PFBS	NA	NA	$3.0×10^{-4}$	$3.0×10^{-4}$	92%	267
Arsenic	1.5	$6.7×10^{-5}$	$3.0×10^{-4}$	$6.7×10^{-5}$	98%	240
Mercury	NA	NA	$3.0×10^{-4}$	$3.0×10^{-4}$	94%	213
Chromium	0.5	$2.0×10^{-4}$	$3.0×10^{-3}$	$2.0×10^{-4}$	97%	160
Uranium	NA	NA	$6.5×10^{-4}$	$6.5×10^{-4}$	90%	154
Cyanide	NA	NA	$6.0×10^{-4}$	$6.0×10^{-4}$	92%	133
2,4,6-Trichlorophenol	0.011	$9.1×10^{-3}$	$3.0×10^{-4}$	$3.0×10^{-4}$	97%	107
PFBA	NA	NA	$1.0×10^{-3}$	$1.0×10^{-3}$	90%	100
Atrazine	0.23	$4.3×10^{-4}$	$2.0×10^{-2}$	$4.3×10^{-4}$	97%	74
Cadmium	NA	NA	$5.0×10^{-4}$	$5.0×10^{-4}$	97%	64
1,2,4-Trichlorobenzene	0.029	$3.4×10^{-3}$	$1.0×10^{-2}$	$3.4×10^{-3}$	84%	46
1,2-Dichloroethane	0.091	$1.1×10^{-3}$	$4.0×10^{-2}$	$1.1×10^{-3}$	96%	36
TCEP	0.02	$5.0×10^{-3}$	$7.0×10^{-3}$	$5.0×10^{-3}$	90%	20
Carbon Tetrachloride	0.07	$1.4×10^{-3}$	$4.0×10^{-3}$	$1.4×10^{-3}$	99%	7.0

[a] WWTP, RO, UV/H_2O_2, DWTP.

Table 2-10. Highest 20 *Train A*[a] ICSS for Well-Studied Contaminants, Assuming *Higher-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF (mg/kg/day)$^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train A Overall Removal	ICSS (mg/kg/day) $^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	96%	20400
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	99%	500
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	99.6%	200
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	96%	40
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99.96%	27
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	99%	15
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.6%	13
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.6%	13
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.8%	5.3
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	99.6%	4.0
1,2,4-Trichlorobenzene	0.029	3.4×10^{-3}	1.0×10^{-2}	3.4×10^{-3}	99%	2.9
Cyanide	NA	NA	6.0×10^{-4}	6.0×10^{-4}	99.8%	2.7
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	99%	2.0
2,4,6-Trichlorophenol	0.011	9.1×10^{-3}	3.0×10^{-4}	3.0×10^{-4}	99.96%	1.3
Atrazine	0.23	4.3×10^{-4}	2.0×10^{-2}	4.3×10^{-4}	99.96%	0.92
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	99.96%	0.80
TDCPP	NA	NA	2.0×10^{-2}	2.0×10^{-2}	99%	0.50
1,2-Dichloroethane	0.091	1.1×10^{-3}	4.0×10^{-2}	1.1×10^{-3}	99.96%	0.36
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	99.996%	0.20
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	99.6%	0.20

[a] WWTP, RO, UV/H_2O_2, DWTP.

Table 2-11. Highest 20 *Train B*[a] ICSS for Well-Studied Contaminants, Assuming *Lower-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train B Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	$2.0{\times}10^{-6}$	$8.0{\times}10^{-6}$	$2.0{\times}10^{-6}$	68%	163200
PFOA	0.07	$1.4{\times}10^{-3}$	$2.0{\times}10^{-5}$	$2.0{\times}10^{-5}$	0%	50000
NMOR	6.7	$1.5{\times}10^{-5}$	NA	$1.5{\times}10^{-5}$	68%	21440
PFOS	NA	NA	$2.0{\times}10^{-5}$	$2.0{\times}10^{-5}$	68%	16000
Cobalt	NA	NA	$3.0{\times}10^{-4}$	$3.0{\times}10^{-4}$	20%	2667
PFBS	NA	NA	$3.0{\times}10^{-4}$	$3.0{\times}10^{-4}$	20%	2667
Arsenic	1.5	$6.7{\times}10^{-5}$	$3.0{\times}10^{-4}$	$6.7{\times}10^{-5}$	84%	2400
Mercury	NA	NA	$3.0{\times}10^{-4}$	$3.0{\times}10^{-4}$	36%	2133
Chromium	0.5	$2.0{\times}10^{-4}$	$3.0{\times}10^{-3}$	$2.0{\times}10^{-4}$	68%	1600
PFBA	NA	NA	$1.0{\times}10^{-3}$	$1.0{\times}10^{-3}$	0%	1000
Cadmium	NA	NA	$5.0{\times}10^{-4}$	$5.0{\times}10^{-4}$	68%	640
Uranium	NA	NA	$6.5{\times}10^{-4}$	$6.5{\times}10^{-4}$	60%	615
1,4-Dioxane	0.1	$1.0{\times}10^{-3}$	$3.0{\times}10^{-2}$	$1.0{\times}10^{-3}$	68%	320
Nickel	NA	NA	$2.0{\times}10^{-2}$	$2.0{\times}10^{-2}$	20%	40
2,6-Dinitrotoluene	1.5	$6.7{\times}10^{-5}$	$1.0{\times}10^{-3}$	$6.7{\times}10^{-5}$	100%	38
TCEP	0.02	$5.0{\times}10^{-3}$	$7.0{\times}10^{-3}$	$5.0{\times}10^{-3}$	90%	20
Selenium	NA	NA	$5.0{\times}10^{-3}$	$5.0{\times}10^{-3}$	90%	20
Carbon Tetrachloride	0.07	$1.4{\times}10^{-3}$	$4.0{\times}10^{-3}$	$1.4{\times}10^{-3}$	97%	18
2,4-D	NA	NA	$5.0{\times}10^{-3}$	$5.0{\times}10^{-3}$	92%	16
Fluoride	NA	NA	$4.0{\times}10^{-2}$	$4.0{\times}10^{-2}$	36%	16

[a] WWTP, Ozonation, Biofiltration, GAC, UV disinfection, DWTP.

Table 2-12. Highest 20 *Train B*[a] ICSS for Well-Studied Contaminants, Assuming *Higher-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train B[a] Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	96%	20400
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	60%	20000
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	96%	2680
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	96%	2000
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	60%	1333
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	60%	1333
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	84%	533
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	60%	400
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	90%	154
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	96%	80
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	96%	40
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	99.6%	20
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	60%	20
Fluoride	NA	NA	4.0×10^{-2}	4.0×10^{-2}	84%	4.0
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	99%	2.0
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	99.99%	1.5
Iodide	NA	NA	1.0×10^{-2}	1.0×10^{-2}	99%	1.0
Copper	NA	NA	4.0×10^{-2}	4.0×10^{-2}	96%	1.0
Selenium	NA	NA	5.0×10^{-3}	5.0×10^{-3}	99.6%	0.80
Barium	NA	NA	2.0×10^{-1}	2.0×10^{-1}	84%	0.80

[a] WWTP, Ozonation, Biofiltration, GAC, UV disinfection, DWTP.

Table 2-13. Highest 20 *Train C*[a] ICSS for Well-Studied Contaminants, Assuming *Lower-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train C Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	74%	130560
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	90%	5000
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	92%	4000
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	97%	2144
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	92%	267
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	92%	267
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	98%	240
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	94%	213
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	97%	160
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	90%	154
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	90%	102
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	90%	100
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	97%	64
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	90%	20
Atrazine	0.23	4.3×10^{-4}	2.0×10^{-2}	4.3×10^{-4}	100%	7.4
TDCPP	NA	NA	2.0×10^{-2}	2.0×10^{-2}	90%	5.0
Carbon Tetrachloride	0.07	1.4×10^{-3}	4.0×10^{-3}	1.4×10^{-3}	99%	4.5
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	92%	4.0
Selenium	NA	NA	5.0×10^{-3}	5.0×10^{-3}	99%	2.0
2,4-D	NA	NA	5.0×10^{-3}	5.0×10^{-3}	99%	1.6
Copper	NA	NA	4.0×10^{-2}	4.0×10^{-2}	99%	0.19

[a] WWTP, Ozonation, Biofiltration, RO, UV/H_2O_2, DWTP.

Table 2-14. Highest 20 *Train C*[a] ICSS for Well-Studied Contaminants, Assuming *Higher-End Threshold* of Removal Categories.

Note that this table identifies contaminants that are recommended for sampling and do not necessarily present a risk to the selected potable reuse train.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train C Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	98%	8160
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	99%	500
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	99.6%	200
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99.96%	27
Uranium	NA	NA	6.5×10^{-4}	6.5×10^{-4}	99%	15
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.6%	13
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.6%	13
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	99.8%	5.3
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	99.6%	4.0
TCEP	0.02	5.0×10^{-3}	7.0×10^{-3}	5.0×10^{-3}	99%	2.0
1,4-Dioxane	0.1	1.0×10^{-3}	3.0×10^{-2}	1.0×10^{-3}	99.8%	1.6
Cadmium	NA	NA	5.0×10^{-4}	5.0×10^{-4}	99.96%	0.80
TDCPP	NA	NA	2.0×10^{-2}	2.0×10^{-2}	99%	0.50
Chromium	0.5	2.0×10^{-4}	3.0×10^{-3}	2.0×10^{-4}	99.996%	0.20
Nickel	NA	NA	2.0×10^{-2}	2.0×10^{-2}	99.6%	0.20
Fluoride	NA	NA	4.0×10^{-2}	4.0×10^{-2}	99.8%	0.040
Arsenic	1.5	6.7×10^{-5}	3.0×10^{-4}	6.7×10^{-5}	99.9999%	0.015
Carbon Tetrachloride	0.07	1.4×10^{-3}	4.0×10^{-3}	1.4×10^{-3}	99.998%	0.011
Copper	NA	NA	4.0×10^{-2}	4.0×10^{-2}	99.96%	0.010
Atrazine	0.23	4.3×10^{-4}	2.0×10^{-2}	4.3×10^{-4}	99.9996%	0.0092

[a] WWTP, Ozonation, Biofiltration, RO, UV/H_2O_2, DWTP.

2.6 Research Gaps

Research gaps were identified by comparing which processes had the highest percentage of contaminants reviewed without representative removal data or applicable QSARs. Biofiltration had the greatest percentage of unknown removals for the reviewed contaminants at 54% (Figure 2-2). Biofiltration in reuse has been well-studied for pharmaceuticals and PFAAs (Sari et al. 2020). However, few other industrial contaminants have been tested for biofiltration removal in the reuse context. Furthermore, few studies carry out BAC pilots long enough for the GAC to be truly exhausted and isolate the biological removal mechanism from adsorption (Dickenson et al. 2018). For some processes (e.g., RO or ozonation), removal is simply and accurately predictable based on molecular structure (Kibler et al. 2020; Dickenson et al. 2009). However, biofiltration removal is more challenging to model because it involves complex mass transfer and biological mechanisms. Thus, biofiltration could be considered a high priority for further reuse research. On the other hand, biofiltration is relatively ineffective at removing industrial contaminants. Biofiltration had Poor removal for 28% of reviewed contaminants. Readily biologically labile contaminants would generally already be removed by the upstream WWTP and ozonation in Train B. Thus, the primary purpose of biofiltration within Train B could be considered the removal of oxidation products generated in ozonation (e.g., NDMA, formaldehyde, assimilable organic carbon) (Bacaro et al. 2019; van der Kooij 1992; Tackaert et al. 2019). For these reasons, biofiltration and ozonation have often been conceptualized as a single treatment process or critical control point (Walker et al. 2016; Thompson and Dickenson

2020).

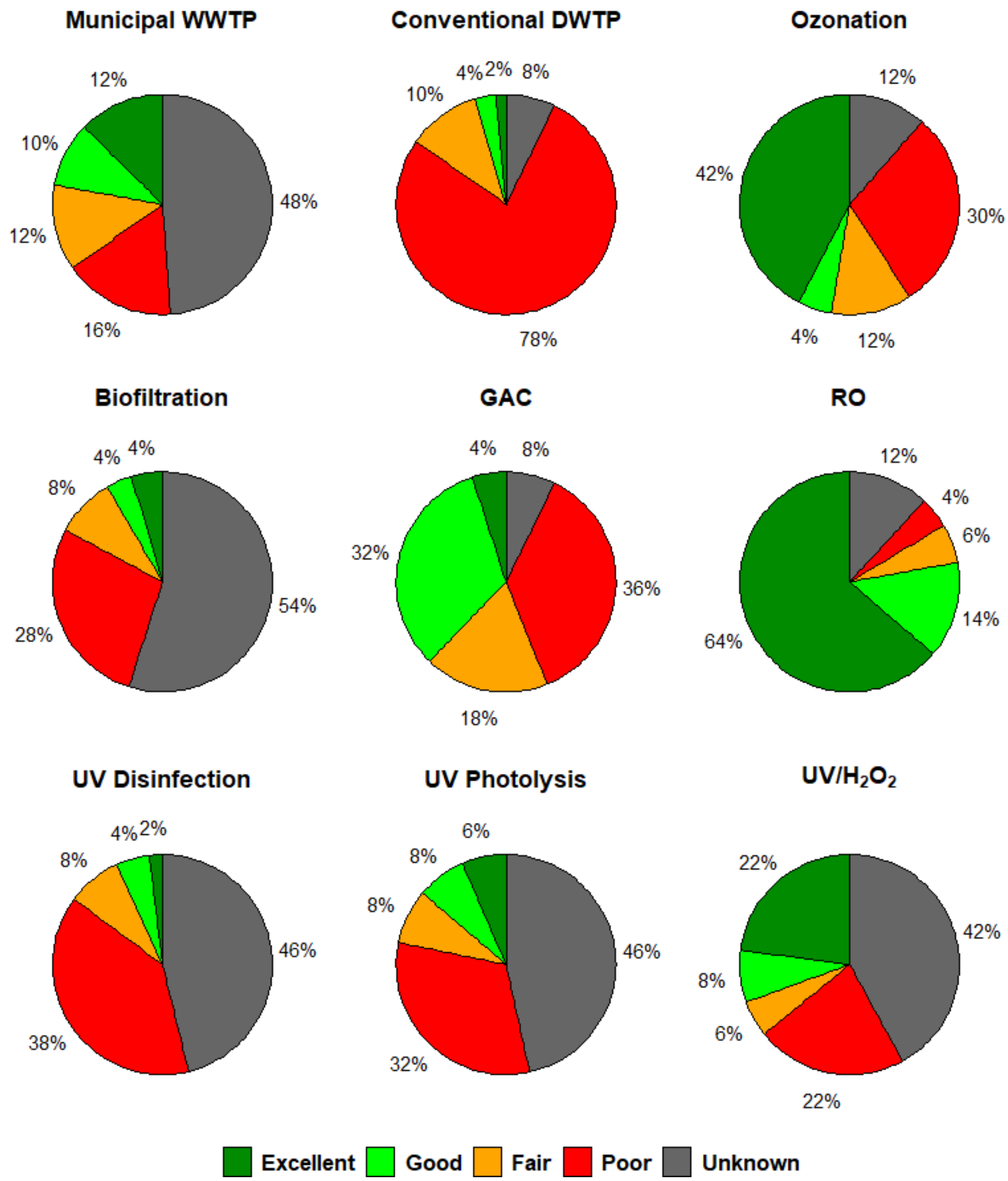

Figure 2-2. Pie Charts of Semiquantitative Removal Categories of 262 Reviewed Contaminants Within Each of Nine Reviewed Treatment Processes.

Excellent, Good, Fair, and Poor include both modeled and experimentally verified removals. Negative removals (i.e., transformation from other contaminants) were included within Poor. Contaminants for which plausible removal under realistic full-scale conditions spanned multiple categories were conservatively classified within the lowest category.

WWTP had the second highest percentage of unknown removals at 48% (Figure 2-2). WWTP trace chemical removal is challenging to model because it depends not only on the biodegradability of the chemical but also sorption to sludge and volatilization (Bhattacharya et al. 1996; Dargnat et al. 2009). Furthermore, WWTPs with biological nutrient removal have both aerobic and anaerobic zones which may facilitate multiple types of biotransformation pathways. Many studies sample WWTP effluent only because this is more directly relevant to the aquatic environment and this matrix is less challenging for analytical chemistry compared to influent. Thus, more research is merited for trace contaminant removal in municipal WWTPs, particularly for solvents and industrial precursors capable of passing through RO (see Section 2.7.5).

To prioritize contaminants for further research, ICSSs were recalculated assuming zero for unknown removals (Tables 2-15 through 2-17). The previous sets of tables only included contaminants with known removals for all processes in the treatment train, so Tables 2-15 through 2-17 encompass a much larger group of contaminants. These tables should be interpreted with caution given that unknown data were utilized in the calculations of these conservative ICSSs; the primary reason for including these tables is to prioritize future research, not prioritize source control. It is not recommended that utilities use Tables 2-15 through 2-17 to establish sampling plans for ESCPs.

Essentially, the contaminants in Tables 2-15 through 2-17 have known high toxicity but data gaps for one or more treatment processes. Based on this approach, 22 new contaminants were identified as research priorities for one or more of the treatment trains. These contaminants are italicized and are the contaminants that are identified in Tables 2-15 through 2-17 but were not included in the previous sets of tables. The majority of these research priorities (14 out of 22) were neutrally charged, low molecular weight compounds from the Solvent & Industrial Precursor family. For example, hydrazine has a more toxic CSF than arsenic and a variety of industrial uses including rocket fuel, reducing agent, and pharmaceutical precursor (Galloway et al. 2020; National Library of Medicine 2020). Based on its molecular weight of only 32 g/mol, it is possible that hydrazine could at least partially pass through RO. Yet, to the best of our knowledge, hydrazine has been virtually unstudied in the context of water treatment. Also highly ranking for research prioritization were a couple metals (lanthanum, thallium) for which partitioning to sludge in WWTPs has not been quantified to the best of our knowledge.

Another commonality among a few of the research priority contaminants was nitro functional groups (1,3-dinitrobenzene, 2,4-dinitrotoluene, nitroglycerin). Nitro functional groups were not included in the QSAR used to estimate RO removal in the absence of experimental data (Kibler et al. 2020). Like halides, nitro groups provide a degree of protection against oxidation because they are electron-withdrawing (Dickenson et al. 2009). However, unlike halides, nitro groups also increase hydrophilicity, reducing sorption removal.

Table 2-15. Highest 20 *Train A*[a] ICSS Conservatively Assuming *No Removal* by Processes without Available Data. *Note table identifies contami*nants that are recommended for further research and are not necessarily recommended for sampling.

Name	CSF $(mg/kg/day)^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Conservative Train A Overall Removal	ICSS $(mg/kg/day)^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	85%	76500
Hydrazine	3	3.3×10^{-5}	NA	3.3×10^{-5}	≥0%	≤30000
1,2,3-Trichloropropane	30	3.3×10^{-6}	4.0×10^{-3}	3.3×10^{-6}	≥95%	≤15000
1,2-Dibromoethane	2	5.0×10^{-5}	9.0×10^{-3}	5.0×10^{-5}	≥40%	≤12000
Vinyl Chloride	0.72	1.4×10^{-4}	3.0×10^{-3}	1.4×10^{-4}	≥0%	≤7200
1,3-Butadiene	0.6	1.7×10^{-4}	NA	1.7×10^{-4}	≥0%	≤6000
1,3-Dinitrobenzene	NA	NA	1.0×10^{-4}	1.0×10^{-4}	≥40%	≤6000
Acrylonitrile	0.54	1.9×10^{-4}	4.0×10^{-2}	1.9×10^{-4}	≥0%	≤5400
Thallium	NA	NA	1.0×10^{-5}	1.0×10^{-5}	≥95%	≤5000
Ethylene Thiourea	0.045	2.2×10^{-3}	2.0×10^{-4}	2.0×10^{-4}	≥0%	≤5000
Ethylene Oxide	0.31	3.2×10^{-4}	NA	3.2×10^{-4}	≥0%	≤3100
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	95%	2500
2,4-Dinitrotoluene	0.31	3.2×10^{-4}	2.0×10^{-3}	3.2×10^{-4}	≥40%	≤1860
Quinoline	3	3.3×10^{-5}	NA	3.3×10^{-5}	≥95%	≤1500
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	97%	1500
Lanthanum	NA	NA	5.0×10^{-5}	5.0×10^{-5}	≥95%	≤1000
Bis(2-Chloroethyl)Ether	1.1	9.1×10^{-5}	NA	9.1×10^{-5}	≥95%	≤550
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99%	503
Urethane	1	1.0×10^{-4}	NA	1.0×10^{-4}	≥95%	≤500
Nitroglycerine	0.017	5.9×10^{-3}	1.0×10^{-4}	1.0×10^{-4}	≥95%	≤500

[a] WWTP, RO, UV/H_2O_2, DWTP.

Table 2-16. Highest 20 *Train B*[a] ICSS Conservatively Assuming *No Removal* by Processes without Available Data.

Note table identifies contaminants that are recommended for further research and are not necessarily recommended for sampling.

Name	CSF (mg/kg/day)$^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Conservative Train B Overall Removal	ICSS (mg/kg/day)$^{-1}$
Thallium	NA	NA	1.0×10^{-5}	1.0×10^{-5}	≥0%	≤100000
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	85%	76500
Hydrazine	3	3.3×10^{-5}	NA	3.3×10^{-5}	≥0%	≤30000
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	45%	27500
Lanthanum	NA	NA	5.0×10^{-5}	5.0×10^{-5}	≥0%	≤20000
1,2,3-Trichloropropane	30	3.3×10^{-6}	4.0×10^{-3}	3.3×10^{-6}	≥95%	≤15000
Bis(2-Chloroethyl)Ether	1.1	9.1×10^{-5}	NA	9.1×10^{-5}	≥0%	≤11000
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	85%	10050
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	85%	7500
Nitroglycerine	0.017	5.9×10^{-3}	1.0×10^{-4}	1.0×10^{-4}	≥55%	≤4500
Ethylene Oxide	0.31	3.2×10^{-4}	NA	3.2×10^{-4}	≥0%	≤3100
Ethylene Thiourea	0.045	2.2×10^{-3}	2.0×10^{-4}	2.0×10^{-4}	≥40%	≤3000
1,3-Dinitrobenzene	NA	NA	1.0×10^{-4}	1.0×10^{-4}	≥73%	≤2700
Cobalt	NA	NA	3.0×10^{-4}	3.0×10^{-4}	40%	2000
PFBS	NA	NA	3.0×10^{-4}	3.0×10^{-4}	40%	2000
Hexachloroethane	NA	NA	7.0×10^{-4}	7.0×10^{-4}	≥0%	≤1429
Antimony	NA	NA	4.0×10^{-4}	4.0×10^{-4}	≥45%	≤1375
2,4,6-Trichlorophenol	0.011	9.1×10^{-3}	3.0×10^{-4}	3.0×10^{-4}	≥64%	≤1200
PFBA	NA	NA	1.0×10^{-3}	1.0×10^{-3}	30%	700
Mercury	NA	NA	3.0×10^{-4}	3.0×10^{-4}	80%	675

[a] WWTP, Ozonation, Biofiltration, GAC, UV disinfection, DWTP.

Table 2-17. Highest 20 *Train C*[a] ICSS Conservatively Assuming *No Removal* by Processes without Available Data.
Note that this table identifies contaminants that are recommended for further research and are not necessarily recommended for sampling.

Name	CSF (mg/kg/day)$^{-1}$	RSD (mg/kg/day)	RfD (mg/kg/day)	Lower Toxicity Metric (mg/kg/day)	Approx. Train C Overall Removal	ICSS (mg/kg/day)$^{-1}$
NDMA	51	2.0×10^{-6}	8.0×10^{-6}	2.0×10^{-6}	91%	45900
Hydrazine	3	3.3×10^{-5}	NA	3.3×10^{-5}	≥0%	≤30000
1,2,3-Trichloropropane	30	3.3×10^{-6}	4.0×10^{-3}	3.3×10^{-6}	≥95%	≤15000
Thallium	NA	NA	1.0×10^{-5}	1.0×10^{-5}	≥95%	≤5000
Ethylene Thiourea	0.045	2.2×10^{-3}	2.0×10^{-4}	2.0×10^{-4}	≥0%	≤5000
Ethylene oxide	0.31	3.2×10^{-4}	NA	3.2×10^{-4}	≥0%	≤3100
1,3-Dinitrobenzene	NA	NA	1.0×10^{-4}	1.0×10^{-4}	≥73%	≤2700
PFOA	0.07	1.4×10^{-3}	2.0×10^{-5}	2.0×10^{-5}	95%	2500
PFOS	NA	NA	2.0×10^{-5}	2.0×10^{-5}	97%	1500
Lanthanum	NA	NA	5.0×10^{-5}	5.0×10^{-5}	≥95%	≤1000
2,4-Dinitrotoluene	0.31	3.2×10^{-4}	2.0×10^{-3}	3.2×10^{-4}	≥73%	≤837
1,2-Dibromoethane	2	5.0×10^{-5}	9.0×10^{-3}	5.0×10^{-5}	≥97%	≤600
Bis(2-Chloroethyl)Ether	1.1	9.1×10^{-5}	NA	9.1×10^{-5}	≥95%	≤550
NMOR	6.7	1.5×10^{-5}	NA	1.5×10^{-5}	99%	503
Beryllium	NA	NA	0.002	2.0×10^{-3}	≥0%	≤500
Epichlorohydrin	0.0099	1.0×10^{-2}	0.002	2.0×10^{-3}	≥0%	≤500
Benzyl Chloride	0.17	5.9×10^{-4}	0.002	5.9×10^{-4}	≥75%	≤425
Vinyl Chloride	0.72	1.4×10^{-4}	3.0×10^{-3}	1.4×10^{-4}	≥95%	≤360
1,3-Butadiene	0.6	1.7×10^{-4}	NA	1.7×10^{-4}	≥95%	≤300
Acrylonitrile	0.54	1.9×10^{-4}	4.0×10^{-2}	1.9×10^{-4}	≥95%	≤270

[a] WWTP, Ozonation, Biofiltration, RO, UV/H_2O_2, DWTP.

2.7 Interference and Pass-Through Hazards

The ICSSs presented in Section 2.5 present a semiquantitative, holistic ranking of all 262 contaminants reviewed in this study. The following section takes a more categorical approach by organizing the reviewed contaminants into three groups: pass-through hazard, interference hazard, both, or neither (none). The definitions for pass-through and interference were based upon the NPP, though with an emphasis on reuse regulations and goals rather than National Pollutant Discharge Elimination System (NPDES) permits for aquatic discharge. Thus, a pass-through hazard is a contaminant that could cause a violation of a reuse rule, guideline, or health goal by exiting the WWTP and advanced treatment at challenging levels in its original chemical state. The threshold set for defining pass-through hazards in this report was less than 90% overall removal by the whole train.

An interference hazard is a contaminant that could inhibit or disrupt the treatment system's processes or operations and cause a violation of a reuse rule or guideline or compromise the safety or suitability of the water for reuse by means other than passing through. Examples of interference hazards included: scavenging an oxidant or disinfectant; inhibiting biodegradation in activated sludge or biofilters; or scaling RO. Contaminants that could biodegrade or oxidize into other chemicals or oxidation states that would be more toxic or stringently regulated (e.g., reduced states of metals or DBP precursors) were also considered interference hazards. Such contaminants could cause a violation by means other than passing through, require an operational change such as reducing oxidant dosage, which could then compromise other treatment goals, or diminish or offset the net removal of the transformation product. For example, PFOS is typically around 50% removed from the aqueous phase in WWTPs by sorption to sludge, but this removal is usually offset by generation from biological precursors (Arvaniti et al. 2014). Interference and pass-through contaminants are referred to herein as *hazards* rather than *risks* because concentration was not included in the definition or criteria; the risk would depend on the site-specific concentrations caused by local industries.

In Appendix A, contaminants are classified as interference hazards, pass-through hazards, or neither, for all three trains. However, only nitrate could be considered a pass-through hazard for Train C, conservatively assuming little denitrification by the WWTP. In one sense, Train C could be considered to have the largest number of interference hazards, because it has the largest number of treatment steps and thus the largest number of contaminants that could interfere with one of more of its processes in isolation. However, in practice, the impacts of most interference hazards would be prevented by upstream treatment or mitigated by downstream treatment. For example, any antibiotic resistant genes (ARGs) caused by antibiotics in the WWTP would be removed by RO (Kantor et al. 2019). As another example, ozonation would convert iodide to stable, nontoxic iodate before it could react with chloramines (added upstream of RO to prevent biofouling) to form highly toxic iodinated DBPs (Allard et al. 2013). Hence, Train C was largely omitted from the discussion below.

The contaminants reviewed in the sections below include potential sources to help focus enhanced source control activities in identifying industrial dischargers. Non-exhaustive examples of applications were cited from PubChem for all chemicals (National Library of Medicine 2020). Potential sources were then inferred from these applications and categorized based on the 59 industry categories of the USEPA's Industrial Effluent Guidelines (EPA 2021c). For select contaminants with high-ranking screening scores, uses and sources were further reviewed based on the scientific literature. Empirical formula, molecular weight, octanol-water partition coefficient (logP), logD at pH 7, pKa, and charge at pH 7) were recorded according to QSARs on Chemicalize.com (Chemicalize 2020). This resource has previously been used to estimate logP or logD in the scientific literature (Simazaki et al. 2015; Thompson and Dickenson 2020). Uses and sources of chemicals are also shown in Appendix A.

2.7.1 Metals

Certain metals such as tin can inhibit activated sludge or biological nutrient removal (Tchobanoglous et al. 2003). However, current NPP or local limits should already prevent this inhibition. The concentrations of metals that would inhibit WWTP biological treatment performance are generally much higher than their USEPA drinking water MCLs (Table 2-18). Thus, limits on metal-emitting industries intended to protect conventional WWTP operation may need to be more stringent for reuse if the metal is an interference or pass-through hazard.

Table 2-18. Example Heterotrophic Inhibition Concentrations and USEPA Primary MCLs for Metals.
Heterotrophic inhibition levels are adapted from Tchobanoglous et al. (2003).

Metal	WWTP Inhibition (µg/L)	USEPA Primary MCL (µg/L)
Arsenic	50	10
Cadmium	1000	5
Total Chromium	10,000	100
Lead	100	15
Mercury	100	2

Metals could also be considered an interference hazard if they oxidize to more toxic forms in advanced treatment. Ozone can convert chromite slag and Cr^{3+} to more toxic Cr^{6+} (van der Merwe et al. 2012; Katsoyiannis et al. 2018). Wastewater effluent ozonation can convert Ag_2S nanoparticles into more toxic dissolved Ag^{1+} (Thalmann et al. 2015). Wastewater treatment can dissolve or desorb solid Uranium(IV) to more toxic dissolved UO_2^{2+} (Camacho et al. 2012). Certain metals such as iron or barium could also interfere by contributing to RO scaling (Ikehata et al. 2018; Ronquim et al. 2018).

Metals are consistently over 90% removed by RO (Hadi et al. 2020; Kryvoruchko and Yurlova 2015; Chung et al. 2014). Metals removal in WWTPs and DWTPs vary widely depending on the specific metal and also whether the metals are predominantly particulate or dissolved (Camacho et al. 2012; Kaegi et al. 2011; Hill et al. 2018). Most dissolved metals pass through biofiltration but manganese can be removed via biological adsorption and oxidation (Dickenson et al. 2018). GAC has poor removal for metals (Cyr et al. 2002; Kim and Jung 2008). Thus, metals are not pass-through hazards for Train A but some metals are pass-through hazards for Train B depending on WWTP and DWTP removal, particularly uranium, cobalt, mercury, cadmium, chromium, nickel, copper, strontium, and zinc (Karvelas et al. 2003; Hargreaves et al. 2018; Camacho et al. 2012; Baeza et al. 2012; Stetar et al. 1993; Lara et al. 2016; Crittenden et al. 2012; Hill et al. 2018; Golbaz et al. 2014; Buzier et al. 2006; Kamei-ishikawa et al. 2013).

Metal finishing was identified as both the most common and the most commonly challenging industrial user type in the WWTP survey (Chapter 3). In the reuse utility case studies, metal finishing was also identified as the only CIU in Altamonte Springs, FL and the most prevalent CIU for the LACSD (Chapter 4). Metal finishing can be a source of several metals with high ICSSs including cobalt, nickel, chromium, copper, and cadmium (Barrera-Díaz et al. 2015; Zamani et al. 2007; Makki et al. 2011; Bhattacharya and Gupta 2013; Njau et al. 2000).

Uranium-containing wastewater is discharged from uranium mining and hydrometallurgy (Liao et al. 2021). Sources of cobalt include electroplating, textile mills, and zinc hydrometallurgy (Zamani et al. 2007; Zhou et al. 2019; Hussein 2013). Sources of mercury include petroleum refineries, zinc smelting, and pharmaceutical manufacturing (Urgun-Demirtas et al. 2012; Chung et al. 2017; Cyr et al. 2002). Cadmium is found in the industrial effluents of battery making, electroplating, and leather tanning (Makki et al. 2011). Chromium-rich industrial effluents can originate from electroplating, metal finishing, and leather tanning (Mandal et al. 2010; Perumalsamy and Arumugam 2013; Bhattacharya and Gupta 2013). Potential nickel sources include galvanic plating, circuit board printing, and zinc hydrometallurgy (Njau et al. 2000; Thomas, Zdebik, and Białecka 2018; Zhou et al. 2019). Industrial applications of copper include pipes, antimicrobial surfaces, and the fungicide copper hydroxide (Sreesai and Sthiannopkao

2009; Barrera-Díaz et al. 2015; Atwood and Paisley-Jones 2017).

2.7.2 Nitrogen

Nitrate is a well-known non-carcinogenic toxin that causes blue baby syndrome and has a USEPA MCL of 10 mg/L (EPA 2020b). Nitrate concentrations in wastewater effluent can be near or above the USEPA drinking water MCL (Hill et al. 2018), depending on the WWTP design and operation. Further, nitrate could be considered a DBP precursor because it can react with chlorine and organic compounds to form oximes, nitro-alkenes, and hydroxamic acids which can then break down into cyanide, another USEPA-regulated toxin (Hooper et al. 2020; Carr et al. 1997). Nitrate occurs in wastewater effluent due to the oxidation of ammonia and organic nitrogen in human waste. Thus, increased nitrate in AWTP influent could be caused indirectly by industrial ammonia spills. Nitrate could also increase due to industrial acid spills because denitrification is inhibited at pH below 7.5 (Glass and Silverstein 1998). Nitrate could be released directly by industries such as Fertilizer Manufacturing. Nitrate is not removed by ozonation, post-ozone BAC, GAC, or UV/H_2O_2 (Trussell et al. 2018; Salveson et al. 2018; Li et al. 2017). In fact, BAC converts ammonia to nitrate and ozone oxidizes nitrite to nitrate, so nitrate could increase across Train B AWTPs (Li et al. 2017). Nitrate removal by RO is good but not excellent (around 80%) and decreases with membrane age (Trussell et al. 2018). Thus, the best protection against nitrate is a combination of ESCP and high-quality biological nutrient removal (BNR) at the WWTP.

Nitrite has a lower USEPA MCL (1 mg/L) than nitrate and also causes blue baby syndrome (USEPA 2020b). Nitrite has been used as a meat preservative (Massey 1997). Nitrite can transform to nitrate in WWTPs, biofiltration, and ozonation (Grady et al. 2011; Li et al. 2017). Like nitrate, nitrite can pass through GAC (Stanford et al. 2019). Nitrite is an ozonation interference hazard because it consumes ozone dose (Yang et al. 2017).

Ammonium is an extremely common industrial chemical, with 16 million metric tonnes used in the United States in 2019 (USGS 2020). Ammonium is not directly toxic at levels in wastewater effluent but could cause health hazards through several indirect mechanisms. For one, ammonium can be oxidized to nitrate through natural or engineered biological processes. Secondly, ammonium reacts with hypochlorite to form chloramines, raising the chlorine dose required to achieve free chlorine disinfection or a free chlorine residual (MWH 2005). Chloramines generally form fewer regulated DBPs, but more NDMA and iodinated DBPs relative to free chlorine (Wang et al. 2016; Furst et al. 2018; Stanford et al. 2019). Like nitrate, ammonia fully or partially passes through ozonation, GAC, and RO (Singer and Zilli 1975; Kalkan et al. 2011; Stanford et al. 2019; Trussell et al. 2018). Ammonium may increase in UV/ H_2O_2 from the mineralization of nitrogen-containing organics (Garcia et al. 2007). However, ammonia may be oxidized by over 90% in biofiltration in typical Train B systems due to the high dissolved oxygen post-ozonation (Li et al. 2017). Thus, ammonium would be an interference hazard for all reuse trains and a plausible Train A pass-through hazard. The best strategy to prevent ammonia pass-through and mitigate its interference effects would be a combination of enhanced source control and high-quality BNR including both nitrification and denitrification.

2.7.3 Other Inorganics

Boron is a possible Train A pass-through hazard considering it passes through conventional DWTPs, RO and UV/H_2O_2 (Trussell et al. 2018; Yilmaz et al. 2011). Its fate in WWTP has not been quantified to the best of our knowledge but it would be expected to pass through if in a soluble form such as boric acid. It is not listed as a pass-through hazard due to its unknown fate through the WWTP. Boron has low toxicity to humans and animals but high toxicity to plants (Nielsen 1997; Reid 2010). Boron has many industrial applications including in glass, alloys, and nuclear shielding (National Library of Medicine 2020). Boron can also occur naturally at high concentrations in certain deep aquifers, resulting in high concentrations in produced water from oil and gas extraction (McDonald et al. 2019).

Several inorganics reviewed are pass-through hazards for Train B, including calcium, chloride, fluoride, barium, and sulfate. Fluoride has a USEPA MCL of 4 mg/L. Sulfate, chloride, and total dissolved solids have USEPA Secondary MCLs, so maintaining palatable taste in the advanced treated water could motivate enhanced source control of inorganics. This is particularly true for high-percentage reuse Train B systems vulnerable to cycling up salts. Industrial sources of fluoride include copper recycling, phosphate fertilizer production, and semiconductor fabrication (Jung et al. 2016; Gouider et al. 2014; Hu et al. 2005). Steel recycling and produced water from hydraulic fracturing are sources of barium (Ferrar et al. 2013; Hunter et al. 2020; Forsido et al. 2020).

Several inorganics pose important interference hazards. Calcium is an interference hazard for Train A because it can increase RO scaling (MWH 2005). Bromide and iodide increase the formation of brominated and iodinated DBPs, respectively, in chlorination and especially chloramination (Krasner et al. 2016; Krasner 2009). Iodinated DBPs would be removed by downstream RO (Fang et al. 2021), but certain low molecular weight brominated DBPs such as bromodichloromethane or dibromochloromethane could pass through (Zeng et al. 2016). Bromide also reacts with ozone to form bromate, which has a USEPA MCL of 10 µg/L and would pass through downstream Train B processes (Soltermann et al. 2017). Iodate has relatively low toxicity and does not increase iodinated DBPs, so oxidizing iodine to iodate with ozone or higher doses of free chlorine is a mitigation strategy (Allard et al. 2013). Soltermann et al. (2016) identified municipal waste incinerators, landfills, and the chemical production industry as the major sources of bromide to WWTPs in Switzerland. Landfills have also been identified as a major source of bromide to a reuse system in Virginia (McDonald et al. 2019). Hladik et al. (2014) found orders of magnitude higher brominated and iodinated DBPs in disinfected wastewater effluent accepting produced water from the oil and gas industry. Other industrial sources of iodide include landfills and LCD display manufacturing (Kim et al. 2018; Han et al. 2016). Sulfide can inhibit sludge settleability or nitrification (Echeverria et al. 1992; Zhou et al. 2014).

2.7.4 Pharmaceuticals

Pharmaceuticals have garnered public and scientific concern because, by design, these compounds are generally capable of having effects on the human body at relatively low concentrations. In particular, hormones used for applications such as birth control (e.g., 17 beta-estradiol) may cause estrogenic effects in vertebrates at relatively low concentrations

(Houtman 2010). Furthermore, antibiotics may increase the presence of ARGs or antibiotic resistant bacteria (ARBs) in WWTPs (Gerrity 2017, Gao et al. 2012; Neyestani et al. 2017). Also, some pharmaceuticals are known DBP precursors (Shen and Andrews 2011). However, only a few pharmaceuticals were found that could pass through Train B, namely gabapentin and ICMs. None of the reviewed pharmaceuticals pass through Train A. Chemotherapy drugs are an emerging concern due to their toxicity and increasing consumption but scarce water treatment data is available (Rabii et al. 2014).

Increases in ARGs and ARBs could be considered a form of interference. In sequencing batch reactors simulating full-scale wastewater treatment, the relative percentage of resistance to sulfamethoxazole and trimethoprim was greater in effluent than influent (Neyestani et al. 2017). Clarithromycin and sulfamethoxazole correlated with the ARGs tetX and tetQ, respectively, in samples collected from various points within a WWTP in China (Liu et al. 2019). Aydin et al. (2015) found a higher number of ARGs in the effluent of an anaerobic sequencing batch reactor fed sulfamethoxazole, tetracycline, and erythromycin than one fed just sulfamethoxazole and tetracycline. Koczura et al. (2012) found that *E. coli* in a river were more resistant to several antibiotics including trimethoprim downstream of a WWTP than upstream.

The opioid methadone is an NDMA precursor with a yield ranging from 23% to 70% depending on the chloramine dose (Hanigan et al. 2015). Methadone accounted for up to 62% of NDMA formation potential in wastewater effluent sampled by Hanigan et al. (2015). Methadone was detected at a median concentration around 40 µg/L in the effluent of a WWTP in New York receiving effluent from a pharmaceutical manufacturer known to produce methadone, whereas the median at other WWTPs was below detection (Phillips et al. 2010). Methadone is expected to have excellent removal by ozonation or RO based on its structure and molecular weight, which could prevent downstream NDMA formation in Trains B and C (Dickenson et al. 2009; Bellona et al. 2004). However, chloramines are often applied upstream of RO in Train A to mitigate biofouling (Lee et al. 2020), and the formed NDMA could subsequently pass through RO (Fujioka et al. 2012).

Gabapentin may be a Train B pass-through hazard. It is an antiepileptic medication that occurred at concentrations ranging from 720 to 79,960 ng/L across four WWTPs in New York state (Oliveira et al. 2015). Gabapentin removal in those four WWTPs ranged from 22% to 98% and averaged 52%. Gabapentin removal with ozonation was 50% with 0.6 mgO3:mgDOC according to Hellauer et al. (2017), which is as expected for a saturated aliphatic (Dickenson et al. 2009). However, over 90% ozonation removal would be expected based on the k_{O3} of 220 1/M/s at pH 7 reported by Lee et al. (2014). Gabapentin in wastewater effluent completely broke through GAC in about 5,000 bed volumes and then stabilized at about 40% biological removal (Altmann et al. 2016). Gabapentin is also photo-resistant (Miklos et al. 2018). Gabapentin has a low molecular weight (171 g/mol) but would be removed excellently by RO due to its zwitterionic charge so it is not a Train A pass-through hazard (Bellona et al. 2004).

ICMs are used to decrease the x-ray transparency of target organs during medical imaging. Examples include diatrizoic acid, iohexol, iopromide, iomeprol, and iopamidol. These compounds are considered nontoxic with proposed DWGs over 1 mg/L and they are designed to be hydrophilic to reduce the risk of bioaccumulation (Busetti et al. 2008; Christiansen 2005). This hydrophilicity makes ICMs challenging to remove with GAC (Thompson and Dickenson 2020). ICMs usually contain three iodide groups and have high molecular weight (>700 g/mol), which results in excellent RO removal. However, similar to fluoride and chloride groups, the iodide groups make ICMs relatively challenging to remove through ozonation (Dickenson et al. 2009; Ning and Graham 2008; Snyder et al. 2014). ICMs are interference hazards if chloramination is employed downstream of UV in Train B or upstream of RO in Train A. While not toxic themselves, ICMs can release iodide (I^-) during UV photolysis or anaerobic biodegradation and this iodide can then react to form highly toxic iodinated DBPs (Section 2.7.3) (Redeker et al. 2014; Tian et al. 2014; Wang et al. 2016). Only one ICM, iopamidol, has been found to react with any disinfectants to form DBPs directly (Wendel et al. 2014). Chloramination results in greater iodinated DBP formation than chlorination because free chlorine can oxidize iodide into iodate, which is stable and does not form DBPs (Wang et al. 2016). Due to their resistance to oxidation and hydrophilicity, ICMs are potential pass-through hazards for Train B, particularly diatrizoic acid.

Nonetheless, most pharmaceuticals reviewed had excellent removal by two or more reuse treatment processes (e.g., fipronil, carbamazepine, estrone) (Appendix A). According to the Ghose filter, most pharmaceutical compounds have logP greater than -0.4 and a molecular weight greater than 180 g/mol (Ghose et al. 1999). Thus, most pharmaceuticals are at least partially removable by activated carbon and well-removed by RO (Bellona et al. 2004; Thompson and Dickenson 2020). Furthermore, around 95% of pharmaceutical compounds are charged (Wang et al. 2015). Thus, these pharmaceuticals are well-removed by modern RO membranes which have charge-functionalized surfaces to enhance ion removal (Bellona et al. 2004).

A USEPA study measuring 185 pharmaceuticals found that hospitals contributed anywhere from 1% to 59% of the pharmaceutical mass load in influents of four wastewater systems in New York state (Oliveira et al. 2015). Pharmaceuticals used for chronic conditions (e.g., gabapentin) or with risk of addiction (e.g., methadone) would generally be ill-suited for enhanced source control due to residential usage. However, ICMs would be relatively feasible to control through enhanced source control because they are administered at hospitals for medical imaging, not prescribed for home use (Christiansen 2005).

2.7.5 Solvents and Industrial Precursors

Solvents and industrial precursors are generally less studied in the context of potable reuse compared to pharmaceuticals or PFAS. Nonetheless, much recent research has been devoted to 1,4-dioxane due to its use as a performance-based indicator for advanced oxidation processes in California reuse regulations (Tackaert et al. 2019). 1,4-dioxane also has a California NL of 1 µg/L, and concentrations above this level have been detected in municipal effluents (Trussell et al. 2018; Stepien et al. 2014; CWB 2021b). 1,4-dioxane is a pass-through hazard for both Trains A and B. Stepien et al. (2014) observed no significant 1,4-dioxane removal in WWTPs or DWTPs. 1,4-dioxane is only partially removed by ozone or biofiltration (Trussell et al. 2018). 1,4-dioxane has a logD of -0.09, so poor GAC removal is expected. It was 74% removed by RO in a simulated industrial surge (Tackaert et al. 2019). UV/ H_2O_2 in reuse systems in California are designed to target 0.5-log (68%) 1,4-dioxane removal (Tackaert et al. 2019). 1,4-dioxane is used as a solvent, stabilizer, and industrial precursor to pharmaceuticals and adhesives (WDHS 2013). It is found as a trace contaminant in lacquers, paints, and some consumer products (WDHS 2013). Thus, plausible industrial sources include Pharmaceutical Manufacturing and Paint Formulating. 1,4-dioxane has been found as an impurity in methanol used for carbon addition in WWTPs (Stepien et al. 2014).

Acetone is another solvent that has gained recent attention in the reuse community due to a well-known, documented pass-through event in a full-scale Train A reuse system in California (Marron et al. 2019). Acetone is thought to have over 90% removal in WWTPs, but nevertheless, acetone or a biological precursor was discharged at high enough concentrations to cause a significant TOC spike in the advanced treated water (Dadakis and Dunivin 2013). Acetone is poorly removed by RO, UV/H_2O_2, and ozonation, and around 50% removed by biofiltration (Tackaert et al. 2019). Acetone would also be expected to have poor GAC removal based on a 0.11 logD. Acetone has no drinking water regulations to the best of our knowledge. It is not very toxic with an RfD of 0.9 mg/kg/day, similar to the 1 mg/kg/day oral chronic reference dose of aluminum (Galloway et al. 2020). However, it could represent a flammability or biological process toxicity hazard at WWTPs (Dadakis and Dunivin 2013).

A later, smaller spike of acetone and TOC at the same full-scale Train A facility was attributed to a known discharges of isopropyl alcohol, which biodegrades to acetone (Debroux et al. 2021b). Isopropyl alcohol can also transform to acetone in ozonation or UV/H_2O_2 and inhibits biological treatment at high concentrations (Xiao et al. 2015; Wu et al. 2008). Thus, isopropyl alcohol is a multi-faceted interference compound that could be a high priority for source control.

Other solvents and industrial precursors, such as 1,4-dithiane, ethylene thiourea, bromochloromethane, 1,1,1,2-tetrachloroethane, 1,1-dichloroethane, 1,1,2-trichloroethane, and nitrobenzene are under-studied, plausible Train A and B pass-through hazards and merit further research. 1,4-dithiane would be expected to have similar removals as 1,4-dioxane based on its similar molecular structure (i.e., a saturated six-member ring but with sulfur instead of oxygen atoms). However, 1,4-dithiane has been virtually unstudied in water treatment contexts. Similarly, ethylene thiourea has been virtually unstudied in water treatment despite its structural properties—low molecular weight, neutral charge, and compact cyclic shape—indicating plausible RO pass-through and its known toxicity comparable to PFAS or radionuclides. Bromochloromethane and 1,1,1,2-tetrachloroethane would be expected to have good RO removal based on their structure but their WWTP and UV/H_2O_2 removals are unknown (Kibler et al. 2020). Acetaldehyde, nitrobenzene, and 1,1-dichloroethane can pass through RO and UV/H_2O_2, but their fate in WWTPs is unknown (Kibler et al. 2020; Marron et al. 2020; Sarathy and Mohseni 2009; Chen et al. 2006; Urama and Mariñas 1997; Wols and Hofman-Caris 2012). 1,1,2-trichloroethane passes through WWTPs and RO but its UV/H_2O_2 removal remains unquantified (Bhattacharya et al. 1996; Rodriguez et al. 2012a).

2,4,6-trichlorophenol is used as a wood preservative and is found in effluents from leather tanning and the pulp and paper industry (Lu et al. 2020; Basu and Wei 1998; Bolobajev et al. 2016). 2,4,6-trichlorophenol could be considered an interference hazard because it is a biological precursor to 2,4,6-trichloroanisole (Agus et al. 2011). 2,4,6-trichloroanisole is a dominant odorous compound in secondary effluent, but would have greater than 90% overall removal in Trains A, B and C (Agus et al. 2011). Like the pesticides alachlor and metolachlor (Section 2.7.7), aniline is an industrial precursor that can form more toxic products in UV photolysis, but would be removed by ozonation before UV in Train B (Mestankova et al. 2016).

2.7.6 PFAS

PFAS have been used for decades in nonstick cookware, stain-resistant fabric, electroplating, food packaging, and aqueous film-forming foam (AFFF) used for firefighting at civilian airports and military air bases (Buck et al. 2012). Due to these many uses, PFAS emissions are expected from a wide range of industries. The term PFAS includes both perfluoroalkyl substances, in which every C-H bond has been replaced by a C-F bond, and polyfluoroalkyl substances, which have both C-F bonds and C-H bonds (Buck et al. 2011). PFAS can be further subdivided based on chain length (i.e., number of carbons) and functional groups such as ethers or sulfonamides. Nonetheless, the common theme among PFAS is numerous C-F bonds. These C-F bonds give PFAS their useful industrial properties, but they also give PFAS their environmental persistence, bioaccumulation in humans, and resistant to most water treatment processes. Among the simplest and most studied PFAS are the perflurocarboxylic acids (PFCAs). Experts have estimated that the global emissions of PFCAs were between 2,610 and 21,400 tonnes from 1951 to 2001 (Wang et al. 2014).

Perfluorooctanoic acid (PFOA) and perfluorosulfonic acid (PFOS) were once the predominant PFAS in industry. However, PFOA and PFOS were voluntarily phased out by industries in the United States in the 2000s due to a growing body of evidence that these compounds cause a multitude of health problems including infertility, miscarriage, low birthweight, cancer, kidney disease, and diabetes (Fei et al. 2009; 2007; Darrow et al. 2014; Steenland and Woskie 2012). Depending on the industrial application, PFOA and PFOS were replaced with related compounds such as short-chain PFAS, polyfluoroalkyl substances, or perfluoroethers (Buck et al. 2012; Hopkins et al. 2018). Despite the voluntary phaseout of PFOS and PFOA production in the 2000s, an electroplating facility was identified as a major source of PFOS to the municipal sewer in Michigan in 2017 (EGLE 2020). PFOA, PFOS, and related long-chain PFAS also still enter municipal sewers via landfill leachate (Masoner et al. 2020b).

PFAS may enter sewers from airports (Houtz et al. 2018). Airports use PFAS-containing firefighting foam and are required by the Federal Aviation Authority to practice firefighting at regular intervals. In cold climates, airports are required to obtain a stormwater permit or discharge stormwater from runways to sanitary sewers due to environmental concerns about deicing fluid (USEPA 2021a). Thus, PFAS from airports could enter sewers via infrastructure intended for deicing fluid. In addition to metals (Section 2.7.1), metal finishing can be a major source of PFAS to sewersheds as well (EGLE 2020; Lin et al. 2014; Buck et al. 2012).

PFAS are poorly removed by coagulation, ultrafiltration, and chlorination (Appleman et al. 2014). In fact, PFAAs often increase during ozonation (Pisarenko et al. 2015), biological wastewater treatment (Becker et al. 2008), and ultraviolet advanced oxidation process (UVAOP) (Anumol et al. 2016) due to transformation of polyfluorinated precursors. Thus, polyfluorinated compounds could be considered interference hazards for Trains A, B, and C. For example, 8:2 fluorotelomer unsaturated carboxylic acid (8:2 FTUCA) can oxidize to PFOA in ozonation or UV/H_2O_2 (Anumol et al. 2016). However, Pisarenko et al. (2015) did not observe significant PFOA increases in ozonation of secondary effluents, and for the trains studied herein, 8:2 FTUCA or the resulting PFOA would be removed by RO or GAC. GAC can remove long-chain PFAS if the replacement or regeneration frequency is sufficient, but they are less effective for short-chain PFAS (Appleman et al. 2014; McCleaf et al. 2017). Currently, RO is the only full-scale technology with proven, reliable, lasting removal of both long and short-chain PFAS. Thus, PFAS, especially short-chain PFAS, would be a pass-through risk for Train B. However, short-chain PFAS are generally thought to be less toxic than their long-chain analogues. For example, the RfD for PFBS is 15 times higher than PFOS (USEPA 2021b).

A treatment-based rather than a chemical-by-chemical approach would be most strategic for PFAS source control. Thousands of new PFAS have been registered since the PFOA and PFOS phaseout (Wang et al. 2017) and new biological intermediates of anthropogenic polyfluorinated compounds are continuously being discovered (Yi et al. 2018). Similar health effects and treatment behavior are likely based on their chemical similarity, to the extent that experts have recommended regulating PFAS as a class (Kwiatkowski et al. 2020; Cordner et al. 2016). Decades may pass between when a specific contaminant is first introduced into industry and when it is first detected in wastewater, and decades more before it is regulated (Cordner, Richter, and Brown 2016). Recent animal-based studies have found comparable toxicity between PFOA and certain substitute PFAS (Blake et al. 2020). Thus, rather than placing local limits on specific known PFAS, reuse utilities could require RO, GAC, or hazard waste disposal of the effluent of PFAS-emitting industries (EGLE 2020). Even with stringent source control, PFAS may still be present in municipal effluent at concentrations above DWGs due to occurrence in residential wastewater (Thompson et al. 2022).

2.7.7 Pesticides

Elevated pesticide concentrations may occur in wastewater due to industrial sources. For example, for three WWTPs in Spain with a total sample size of 24, the median effluent atrazine concentration was 7.4 ng/L but the maximum was 732 ng/L (Köck-schulmeyer et al. 2013). Similarly, in the same study, simazine had a median concentration of 12.5 ng/L but a maximum concentration 1990 ng/L. These pesticide concentration outliers could be explained by transient industrial emissions. Furthermore, Rodríguez et al. (2012b) found a significantly higher median concentration of 2,4-D in the effluent of one WWTP compared to another in Australia, an indicator of a local industrial pesticide source.

No pesticides reviewed would be expected to pass through Train A. All pesticides reviewed would be removed by RO due to charge or high molecular weight except for 1,3-dichloropropene and acephate. UV/H_2O_2 would have excellent acephate removal based on a k_{OH} over 5.5×10^9 1/M/s (Parker et al. 2017). No studies were found on the hydroxyl radical oxidation of 1,3-dichloropropene, but its C=C double bond would be susceptible to oxidative attack by ozone and thus presumably also hydroxyl radical (Dickenson et al. 2009).

No pesticides were confirmed Train B pass-through hazards based on the criterion of less than

90% removal by the whole train. However, 2,4-dichlorophenoxyacetic acid (2,4-D) had less than 90% removal by ozonation, biofiltration, or GAC individually (Benitez et al. 2004; Shimabuku et al. 2019; Coelho and Do Rozário 2019). Furthermore, several pesticides had insufficient treatment studies available but similar properties as 2,4-D (i.e., hydrophilicity, negative or neutral charge, and chloride functional groups or an absence of ozone-susceptible functional groups). Pesticides fitting this description included acephate, dicamba, ethephon, and glufosinate. Thus, these pesticides merit further research to ascertain their removal by Train B processes.

However, several pesticides are interference hazards for both trains due to transformation to more toxic or more challenging to remove products. Souissi et al. (2013) found that the UV photolysis products of metolachlor and alachlor were more toxic to aquatic indicator organisms than the respective parent pesticides. However, in Train B, alachlor would have Excellent removal by GAC and metolachlor would have Excellent removal by ozonation before UV photolysis (Pirbazari et al. 1991; NWRIet al. 2003). Mancozeb (oral chronic reference dose 1.6×10^{-2} mg/kg/day) reacts with ozone to form the orders of magnitude more toxic compound ethylene thiourea (oral chronic reference dose 8×10^{-5} mg/kg/day) (Hwang et al. 2003). Metam biodegrades to methyl isothiocyanate (MITC) in soil (Triky-Dotan et al. 2010), so it plausibly also biodegrades to MITC in wastewater. Metam is also known to photolyze to MITC under UV irradiation (Draper and Wakeham 1993). This transformation is problematic because MITC passes through RO and UVAOP (Swancutt et al. 2010; Debroux et al. 2021a). Atrazine (oral chronic reference dose 3.5×10^{-2} mg/kg/day) biodegrades to hydroxyatrazine and deethylatrazine, including in biofiltration (Selim and Wang 1994). Hydroxyatrazine is somewhat more toxic than atrazine (oral chronic reference dose 1.0×10^{-2} mg/kg/day). Deethylatrazine is equally toxic as atrazine, has been recommended as a health-based indicator for reuse, and is a plausible pass-through hazard for Train B based on its logD (Rauch-Williams et al. 2018; Hollender et al. 2009; Selim and Wang 1994; Thompson and Dickenson 2020).

2.7.8 Other Organics

N-nitrosomorpholine (NMOR) is a Train B pass-through hazard. The sources of NMOR are unclear, though it may be an environmental transformation product of morpholine, which is a solvent and industrial precursor used in the manufacture of lubricants, rubber, and pharmaceuticals (Glover et al. 2019; National Library of Medicine 2020). NMOR has 50% removal in activated sludge (Krauss et al. 2009). NMOR has <10% removal by biofiltration or realistic ozone doses and breaks through GAC by over 20% in under 5,000 bed volumes (Glover et al. 2019). NMOR is 81-84% removed by RO (Fujioka et al. 2012). NMOR is 90% removed by UV at a dose of 325 mJ/cm^2, which is higher than credited UV disinfection but below typical UV/H_2O_2 (Glover et al. 2019).

The flame retardants tris(2-chloroethyl) phosphate (TCEP) and tris(1,3-dichloro-2-propyl) phosphate (TDCPP) ranked highly in the ICSS analyses in Section 2.5 due to their high toxicity. However, these would not meet the criterion for pass-through hazards due to their excellent removal by RO and GAC (Kim et al. 2007; Salveson et al. 2018; Sundaram et al. 2020).

2.7.9 Interference and Pass-Through Summary

Identified pass-through hazards for Trains A, B and C are listed in Table 2-19. As discussed in the introduction to Section 2.7, only nitrate could be considered a Train C pass-through hazard. The criterion for pass-through hazards was less than 90% combined removal for each train. There is overlap between the Train B pass-through hazards in this table and the highest ICSS listed in Section 2.5. The difference, though, is that the ICSS factored in toxicity, while the pass-through hazard categorization did not. Though certain contaminants that met the Train B pass-through hazard criterion would be relatively nontoxic (e.g., calcium), they could nevertheless contribute to secondary MCL challenges such as total dissolved solids. Thus, it would be advisable for utilities planning potable reuse to monitor for the contaminants in Table 2-19 in addition to the highest ICSS contaminants for their treatment train.

Table 2-19. Pass-Through Hazards for Trains A, B and C.

Contaminant	Train A Pass-Through	Train B Pass-Through	Train C Pass-Through
1,4-Dioxane	✓	✓	
Aluminum		✓	
Barium		✓	
Cadmium		✓	
Calcium		✓	
Chloride		✓	
Chromium		✓	
Cobalt		✓	
Copper		✓	
Diatrizoic Acid		✓	
Fluoride		✓	
Gabapentin		✓	
Mercury		✓	
Nickel		✓	
Nitrate	✓	✓	✓
N-Nitrosodimethylamine (NDMA)	✓	✓	
N-Nitrosomorpholine (NMOR)		✓	
Perfluorobutane Sulfonic Acid (PFBS)		✓	
Perfluorobutanoic Acid (PFBA)		✓	
Perfluorodecanoic Acid (PFDA)		✓	
Perfluoroheptanoic Acid (PFHpA)		✓	
Perfluorohexane Sulfonate (PFHxS)		✓	
Perfluorohexanoic Acid (PFHxA)		✓	
Perfluorononanoic Acid (PFNA)		✓	
Perfluorooctanoic Acid (PFOA)		✓	
Perfluorooctane Sulfonic Acid (PFOS)		✓	
Perfluoropentanoic Acid (PFPeA)		✓	
Strontium		✓	
Sulfate		✓	
Uranium		✓	
Zinc		✓	

Potential interference hazards identified for Trains A, B, and C are shown in Table 2-20. Single checkmarks (✓) indicate an interference with a process in the train that is likely mitigatable with existing upstream or downstream treatment. Double checkmarks (✓✓) indicate interferences that would require more research or would likely require source control if measured at problematic levels.

Table 2-20. Potential Interference Hazards for Trains A, B, and C.

Contaminant	Train A	Train B	Train C	Explanation	Mitigation or Solution
Chromium(III)	✓	✓✓	✓	Cr(III) oxidizes to more toxic Cr(VI) with ozonation or UV/ H_2O_2	All oxidation states of chromium would be removed by RO in Trains A or C. Chromium above health goals in Train B would require source control.
Silver (Ag_2S Nanoparticles)		✓	✓	Ag_2S nanoparticles oxidize with ozonation to more toxic dissolved Ag_2SO_4	WWTP has Excellent removal of silver nanoparticles.
Tin	✓✓	✓✓	✓✓	Inhibits biological P removal in WWTP	Source control.
Uranium(IV)	✓	✓✓	✓	Dissolves or desorbs solid U^{4+} to more toxic dissolved UO_2^{2+} in WWTP activated sludge	For Trains A and C, would be removed by RO. May require source control in Train B.
Scalants (i.e., Barium, Iron, Calcium)	✓✓		✓✓	Scale RO	Increase antiscalant. Source control if concluded to impact RO despite antiscalant.
Ammonia	✓	✓	✓	Oxidizes to nitrite or nitrate and consumes free chlorine during WW treatment or chlorination,	Thorough nitrification recommended in WWTPs before reuse.
Nitrite		✓	✓	Consumes ozone dose, oxidizes to nitrate	Thorough nitrification recommended in WWTPs before reuse.
Bromide	✓✓	✓✓	✓✓	Forms bromate and brominated DBPs during ozonation, chlorination, or chloramination	Source control.
Iodide	✓	✓✓	✓	Forms iodinated DBPs during chloramination	Iodide and iodinated DBPs would be removed by RO in Trains A and C (Fang et al. 2021). Train B could require source control or oxidation to iodate.
Sulfide	✓✓	✓✓	✓✓	Inhibits WWTP sludge settleability and nitrification	Source control.
Alachlor		✓		UV photolysis products more toxic to indicator organisms	Excellent removal by GAC before UV in Train B.
Atrazine	✓	✓	✓	Biodegrades to hydroxyatrazine and deethylatrazine in WWTP or biofiltration	In Trains A and C, deethylatrazine and hydroxyatrazine would be removed by RO (Tepuš et al. 2009; Dražević et al. 2011). In Train B, ozonation would transform atrazine to products that would not biodegrade to hydroxyatrazine but could plausibly biodegrade to deethylatrazine (Acero et al. 2003). Deethylatrazine would have expected good removal in both GAC and UV for >90% overall removal downstream of biofiltration in Train B (Prosen and Zupančič-Kralj 2005).

(Continued)

Table 2-20. Continued.

Contaminant	Train A	Train B	Train C	Explanation	Mitigation or Solution
Mancozeb		✓✓	✓✓	Transforms to more toxic ethylene thiourea during ozonation	More research needed on both mancozeb and ethylene thiourea.
Metam	✓✓	✓✓	✓✓	Biodegrades and photolyzes to MITC during WW treatment, which can pass through RO	Source control.
Metolachlor		✓		Photolyzes to more toxic products in UV	Ozonation would remove metolachlor before UV.
8:2 Fluorotelomer unsaturated carboxylic acid (8:2 FTUCA)	✓	✓	✓	Transforms to PFOA in ozonation and UV/ H_2O_2	8:2 FTUCA would be removed by RO before UV/H_2O_2 in Trains A and C. PFOA would be removed by GAC after ozonation in Train B.
Antibiotics (Clarithromycin, Sulfamethoxazole, Erythromycin)	✓	✓✓	✓	Correlated with ARGs	ARGs are removed by RO in Train A and C but require more research in Train B.
ICMs (Diatrizoic Acid, Iohexol, Iomeprol, Iopamidol, Iopromide)	✓	✓✓	✓	Release iodide in UV or anaerobic wastewater, which could then contribute to iodinated DBPs in chloramination	ICMs, iodide, and iodinated DBPs would be removed by RO in Trains A and C (Fang et al. 2021). Train B could require source control or oxidation of released iodide to iodate if iodinated DBPs are attributed to ICMs.
Methadone	✓✓	✓	✓	NDMA precursor during chloramination	Ozonation would destroy methadone prior to chloramination in Trains B and C. May require source control or public outreach and education if NDMA exceedances are attributed to methadone in Train A.
2,4,6-Trichlorophenol	✓	✓	✓	Biodegrades to odorous 2,4,6-trichloranisole during WW treatment	2,4,6-trichloranisole is removed >90% downstream in Trains A, B, and C.
Acetone	✓	✓	✓	Flammable, inhibitory to microbial community, odorous, has caused transient exceedance of CA TOC target.	Excellent removal by WWTP but Poor to Fair removal by advanced processes. May require source control on itself or its precursors if detected despite high WWTP removal.
Aniline		✓		Greater mutagenicity after UV photolysis	Excellent removal by Ozonation before UV in Train B.
Isopropyl Alcohol	✓✓	✓✓	✓✓	Biodegrades to acetone. Oxidizes to acetone in ozonation or UV/H_2O_2. Toxic to biological treatment at high concentrations.	Source control.

2.8 Summary

Contaminants were reviewed for pass-through or interference in conventional and advanced treatment processes to identify priorities for research or enhanced source control for communities implementing potable reuse. Three treatment trains were considered: Train A (MF/RO/UV-H_2O_2), Train B (ozonation/BAC/GAC/UV), and Train C (ozonation/BAC/MF/RO/UV-

H_2O_2). Removal by upstream wastewater treatment and downstream conventional drinking water treatment were also considered in the assessment. ICSSs were calculated based on overall removal and toxicity. High known ICSSs were used to prioritize contaminants for enhanced source control. High possible ICSSs were used to prioritize contaminants for future research where removals in advanced treatment processes were unknown. Key findings of this literature review include:

- Based on current toxicological and water treatment data, the highest priorities for ESCP for reuse should be NDMA, PFAS, NMOR, and metals for the three trains evaluated.
- Ninety-three of the contaminants reviewed lacked published values for the toxicity metrics (CSF or RfD). Many contaminants lacked treatment data or an applicable QSAR for at least one common reuse process. Thus, more toxicological and water treatment research is needed to inform ESCP. Particularly notable research gaps include WWTP and biofiltration treatment of specific contaminants at realistic concentrations, and toxicity data for PFAS other than PFOA, PFOS, PFBA, and PFBS.
- Metal finishing could merit particular attention for ESCP because this CIU is both highly prevalent (Chapters 3 and 4) and a potential source of PFAS, NDMA precursors, and metals such as nickel, chromium, cadmium, cobalt, and copper.
- Short-chain PFAAs (e.g., PFBS, PFHxA) are pass-through risks for Train B. Polyfluorinated compounds are interference risks because they can form short-chain PFAAs in biological or oxidative treatments.
- Few pharmaceuticals pose pass-through hazards, though ICMs could increase iodinated DBPs in systems with UV followed by chloramination.
- Few if any pesticides pose pass-through hazards, but transformations products such as MITC from metam or hydroxyatrazine from atrazine may have greater pass-through potential or toxicity than the parent compound.
- Iodide and bromide are important DBP precursors that may enter sewers from waste incineration, landfills, or the oil and gas industry.
- 1,4-dioxane, nitrate, and NDMA were the only known Train A pass-through hazards identified. However, other Train A pass-through hazards are plausible but have key research gaps (e.g., unknown RO removal, or known RO pass-through and scarce data for other processes). These include ethylene thiourea; 1,4-dithiane; boron; bromochloromethane; 1,1,1,2-tetrachloroethane; 1,1-dichloroethane; 1,1,2-trichloroethane; and nitrobenzene. These contaminants should be prioritized for Train A pilot-scale treatment studies.
- Other contaminants identified as priorities for future treatment research based on their potential ICSS (assuming Poor removal for the research gaps) were 1,2,3-trichloropropane; 1,2-dibromoethane; 1,3-butadiene; 1,3-dinitrobenzene; 2,4,6-trichlorophenol; 2,4-dinitrotoluene; acrylonitrile; antimony; benzyl chloride; beryllium; bis(2-chloroethyl)ether; epichlorohydrin; ethylene oxide; hexachloroethane; hydrazine; lanthanum; nitroglycerin; quinoline; thallium; urethane; and vinyl chloride.
- The number of contaminants included in this analysis highlights the sheer number of industrial contaminants that are potential risks to potable reuse systems. This highlights the need for a robust understanding of new contaminants created and routine updates to this analysis to identify contaminants that merit monitoring or research.

CHAPTER 3

WWTP Survey

The second primary task of this project was to conduct a survey of WWTPs to identify the prevalence of different types of industries that contribute to WWTP collection systems. Ninety-three WWTP utilities were contacted to participate in the survey and answers were received from 80 utilities. The participating utilities are included in the acknowledgments of this report. Both small and large utilities were targeted with this survey to understand how different types of utilities approach and experience industrial contaminants.

There are a relatively small number of operational potable reuse facilities in the world. As such, the majority of the utilities that responded to the survey do not operate potable reuse facilities. Many operate non-potable reuse systems or have other elements that can be categorized as components of a One Water (see definition in Chapter 1) system, but those are different from potable reuse systems. While the goals of the project are to understand the impact of industrial contaminants on potable reuse systems, this survey was forced to take a broader approach, as defined in the objectives outlined in the following subsection, based on the targeted utilities for the survey. Where possible, survey results are differentiated between utilities that currently operate potable reuse systems and utilities that do not. But it is important to keep in mind that many of the answers to the survey do not necessarily reflect potable reuse systems and are more indicative of general WWTP operation. The next chapter of this report provides case studies that are specific to potable reuse systems.

This chapter provides a summary of the results of the survey, with all data reported anonymously so that individual utilities cannot be directly identified. The raw data from the survey is also included in Appendix B as a searchable database so that the reader can further evaluate the results of the survey. Information that is proprietary to each utility was removed from the database to protect the anonymity of each utility. Note that while many of the figures in this chapter identify utilities by number (Utility 1, Utility 17, etc.), a utility identified as "Utility 10" in one question may not be the same as "Utility 10" in another question. Similarly, Appendix B lists the utilities by number but "Utility 1" in Appendix B is not "Utility 1" in the figures in this chapter. The project team greatly appreciates the time that each utility contributed to this project by responding to the survey and wishes to protect answers from scrutiny.

3.1 Survey Objectives and Methods

3.1.1 Survey Objectives

The survey consisted of 55 questions that focused on the impact of industrial contaminants on WWTPs. The primary objectives of the WWTP survey were to:

- Understand the prevalence of different types of industries that contribute to WWTP collection systems.
- Identify if there are specific contaminants, or groups of contaminants, that consistently

pose problems to WWTP operation.
- Understand the general framework for pretreatment programs and ESCPs.

The survey was meant to provide a broad understanding of the impact of industries and industrial contaminants on WWTP systems. The data provides a snapshot of systems, mainly across the United States, but falls short of providing actionable information. The case studies, discussed in Chapter 4 of this report, provide more specific detail on a small set of utilities that were selected for follow-up interviews based on the results of the survey.

3.1.2 Survey Methods

The survey was generated using Microsoft Forms, an easy-to-use web-based survey platform. This platform made it easy to design a custom survey with different types of questions and provided for one-click access to the survey for the respondents. It also provided an easy download of survey results for data management. Utilities were sent a link to the survey and were asked to respond within 6 weeks.

While Microsoft Forms was a suitable survey method, several drawbacks to this platform were identified:

- The survey required a single individual to respond to all survey questions. Many utilities required a team of people to answer the survey questions and there was no way in Microsoft Forms to have multiple people fill out the same survey. Thus, a point person was required for each utility to answer the survey.
- Microsoft Forms does not offer a "save and return later" option for answering the survey, so all answers needed to be provided in a single browser session. As many utilities needed several days to answer to all survey questions, this provided a challenge.
- Many utilities preferred to have a written list of questions that could easily be copied and pasted into an email to help get answers to specific questions. The survey made this difficult.

Our team ended up providing all utilities with a Microsoft Word and a PDF version of the survey questions in addition to the online link. Many utilities decided to fill out the Word or PDF versions instead of the browser version and our team entered the information into Microsoft Forms for data analysis purposes. In the end, using an online survey was beneficial for our team but some key functionality would have helped the utilities answer the survey more easily.

3.2 Survey Participants

This section provides information on the utilities that responded to the survey and the types of potable reuse and One Water programs that each utility operates. This high-level information was needed to provide context on the more detailed pretreatment and ESCP questions that were asked later in the survey.

3.2.1 Number of Utilities and WWTPs Represented

A total of 93 utilities, mainly representing major metropolitan cities, were identified to participate in the survey. The vast majority of the utilities identified were located in the United States; in fact, only three utilities outside of the United States were sent the survey (with two responding). This is primarily due to our project team and our agency partners being in the United States, but it also reflects that many of the questions ask about characteristics of each utility's NPP, which is an EPA program. The locations of the utilities in the United States that responded to the survey are shown on Figure 3-1 to provide a geographic understanding of the responses.

Of the 93 utilities that received the survey, 80 utilities completed it. The survey response rate was higher than anticipated and reflects the interest and importance of this research and the commitment of the utilities to provide valuable information. Those 80 utilities collectively represent 355 WWTPs. Ninety-one percent of the participating utilities indicated they have an industrial pretreatment program (79 out of 80 participants responded to this question). Pretreatment programs are intended to monitor and prevent the introduction of difficult-to-treat non-domestic pollutants into WWTPs. While the NPP only regulates WWTPs with capacities greater than 5 mgd, 8 of the 12 utilities with WWTP flows less than 5 mgd responded that they have a pretreatment program.

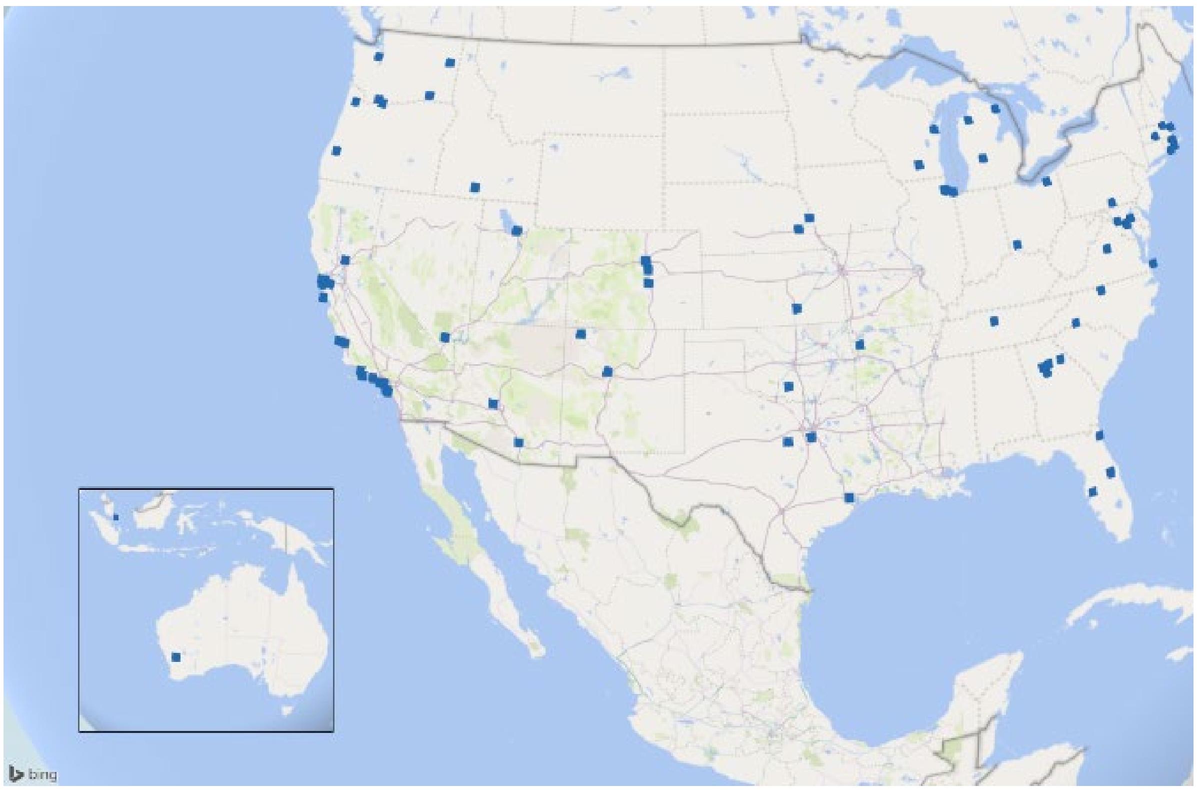

Figure 3-1. General Locations of Utilities Identified to Participate in the Survey.

3.2.2 WWTP Capacity Represented

The total design wastewater treatment capacity of all 80 participating utilities was 11.96 billion gallons per day. The treatment capacity for each participating utility varied from as little as 0.25 mgd to 1,967 mgd. The breakdown of WWTP capacities for all survey respondents is shown on Figure 3-2. The median design capacity of the 80 utilities was 45 mgd, meaning that this survey skewed toward larger utilities. However, 10 utilities that responded to the survey have a total design capacity under 5 mgd.

Figure 3-3 shows the relationship between the average treatment flow and the design capacity. While this does not have a direct impact on industrial contamination, our team felt this provided interesting information for the participating utilities. Most utilities observed a monthly average treatment flow that was greater than 50 percent of their design average monthly treatment capacity; 63 out of the 74 utilities that responded to the question have average flows between 40 and 90 percent of the design flow.

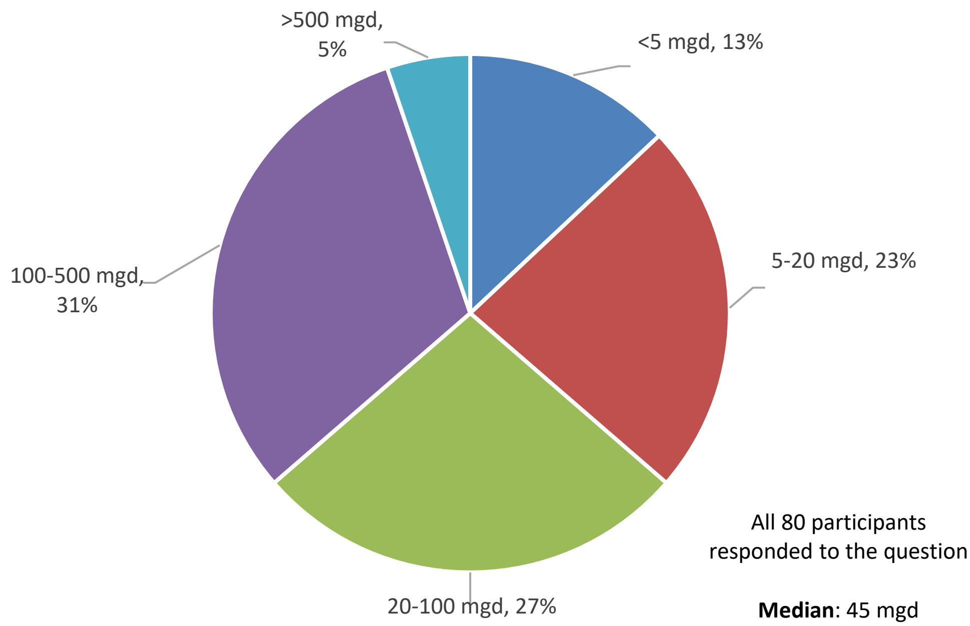

Figure 3-2. Total Treatment Capacity for Each Utility (mgd).

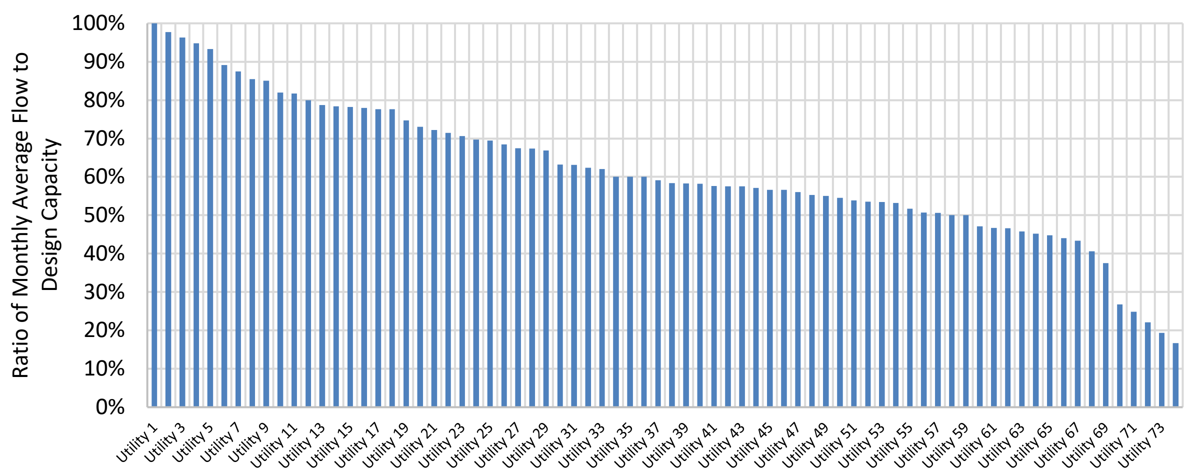

Figure 3-3. Relationship between the Average Treatment Capacity and the Design Capacity.

Survey responses represent a total of 61 million customers (nearly 20 percent of the U.S. population) and 7.9 million service connections. The number of customers per utility and the number of service connections per utility are shown on Figures 3-4 and 3-5, respectively.

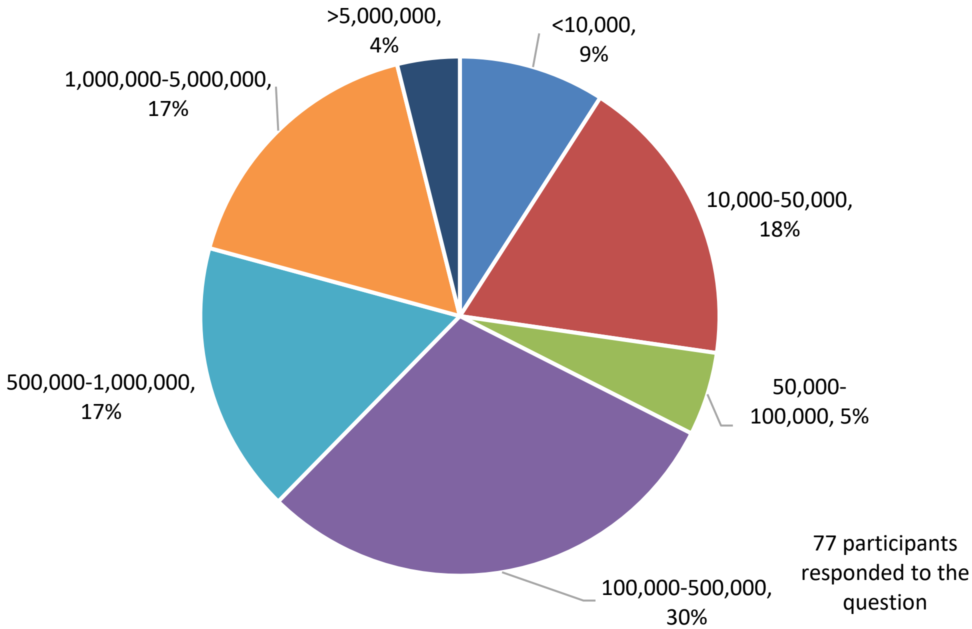

Figure 3-4. Total Number of Customers Represented per Utility.

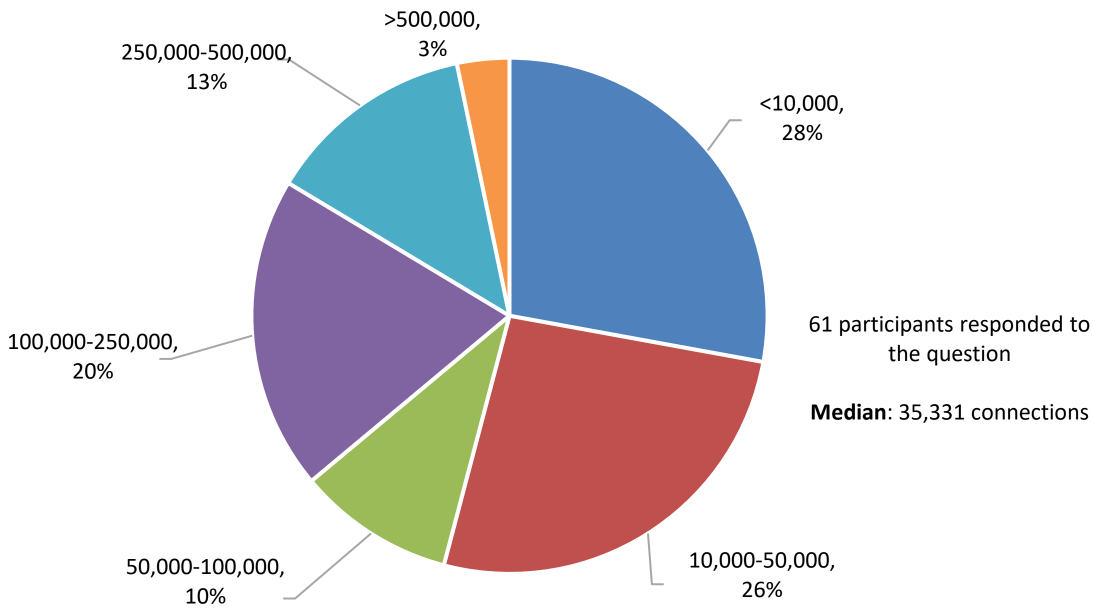

Figure 3-5. Total Number of Service Connections per Utility.

3.2.3 Potable Reuse and One Water Programs

The major objectives of this project focus on the impact of industrial contaminants on potable reuse. The next set of questions asked about utilities' participation in potable reuse and other One Water initiatives. Of the participating utilities, 81 percent participate in One Water initiatives at their treatment facilities. One Water initiatives were broken down into the six categories that are shown on Figure 3-6 (the project team hypothesized these six types of programs would be the most common). The results show that non-potable reuse is the most prevalent One Water initiative, followed by biosolids recovery, stormwater management, and biogas recovery. Figure 3-5 shows the total number of participants utilizing each type of One Water initiative. Seventeen utilities participate in a potable reuse program.

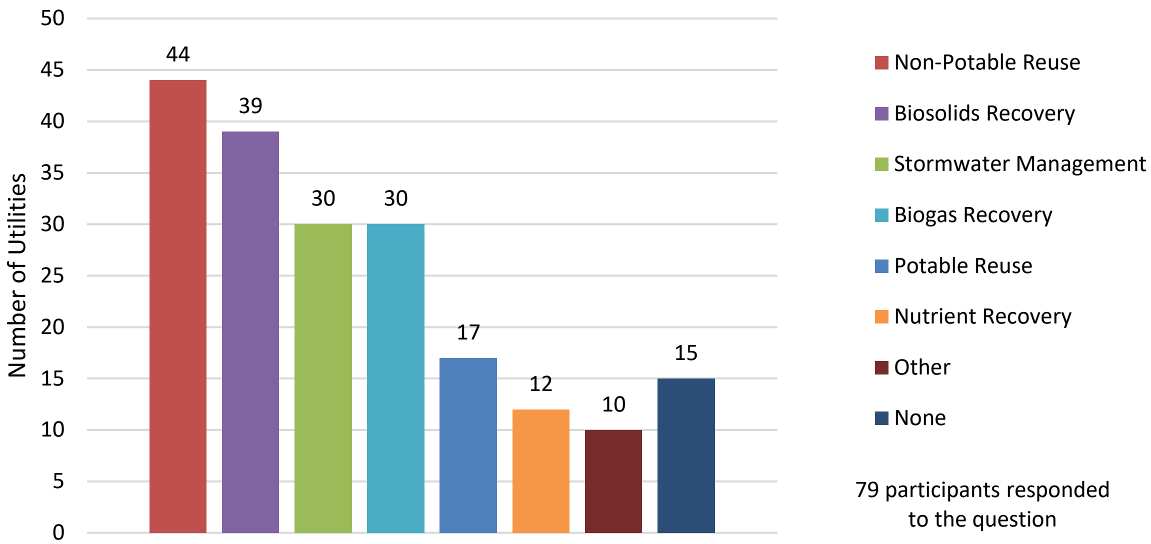

Figure 3-6. Total Number of Participating Utilities Using Each Type of One Water Initiative.

Figures 3-7 and 3-8 show the relationship between potable and non-potable reuse flows versus average WWTP flows, respectively. Only eight utilities reported the capacity of their operational potable reuse facilities, and two of those utilities operate demonstration-scale facilities that have significantly less capacity than the WWTPs. Of the six that practice full-scale potable reuse, flows range between 23 and 61 percent of the average WWTP flow.

Figure 3-8, however, tells a different story. Of the 44 utilities that reported their non-potable reuse flows, 12 have 100 percent of the WWTP flow contributing to the non-potable system and the median value was greater than 50 percent. These two figures show the wide gap between adoption of non-potable reuse compared to potable reuse.

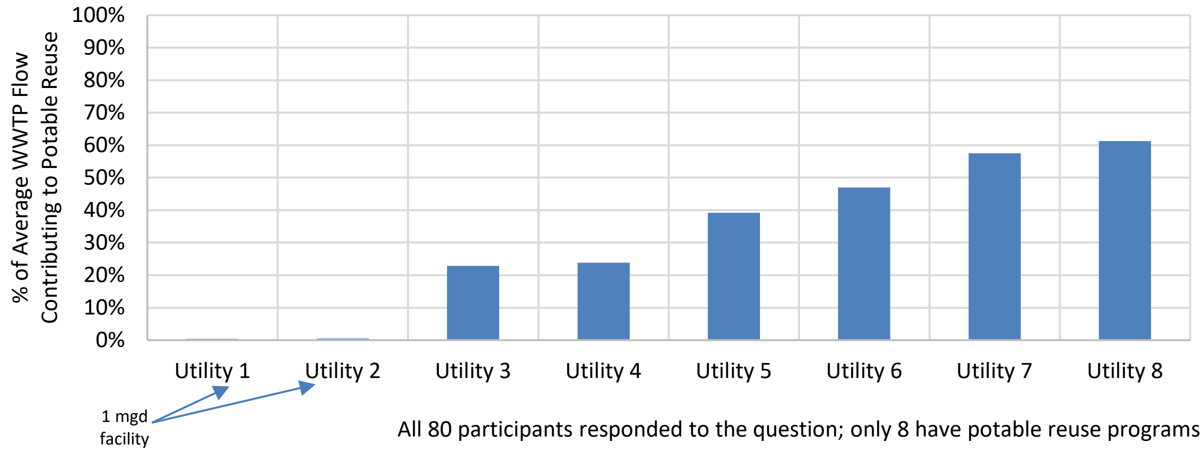

Figure 3-7. Percent Relationship between Potable Reuse Flows and Average WWTP Flows for the Utilities that Participate in Potable Reuse.

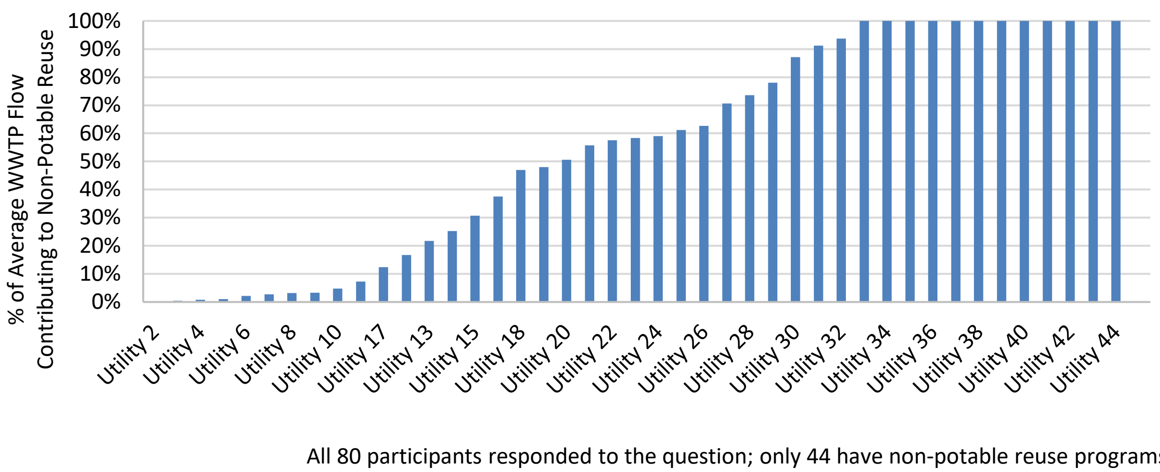

Figure 3-8. Percent Relationship between Non-Potable Reuse Flows and Average WWTP Flows for the Utilities that Participate in Potable Reuse.

The survey also asked if utilities that have multiple WWTPs operate each WWTP independently or if there is a coordinated strategy between the WWTPs for flow management, One Water, or other purposes. Of the participating utilities, 40 operate more than one WWTP. Of those 40 utilities, 14 operate their treatment plants completely independently. The other 26 utilities have some degree of integrated strategy between WWTPs, with most of the coordination involving solids handling.

3.3 Survey Results

3.3.1 Industrial Pretreatment Program Characteristics

Figures 3-9, 3-10, and 3-11 show the total number of permitted IUs, SIUs, and CIUs across survey participants, respectively. Nearly 60,000 permitted industries were accounted for in this survey, with approximately three-quarters of all permits coming from just three utilities.

A total of 25 participating utilities indicated that they also focus on industries that are not SIUs or CIUs, including seven of the eight participating utilities that actively practice potable reuse. Figure 3-12 shows the different types of permitted industries that do not fall into the significant or categorical categories. Food and beverage industrial dischargers are the most common industrial category that utilities permit as SIUs even when the regulations do not mandate that they be considered SIUs or CIUs.

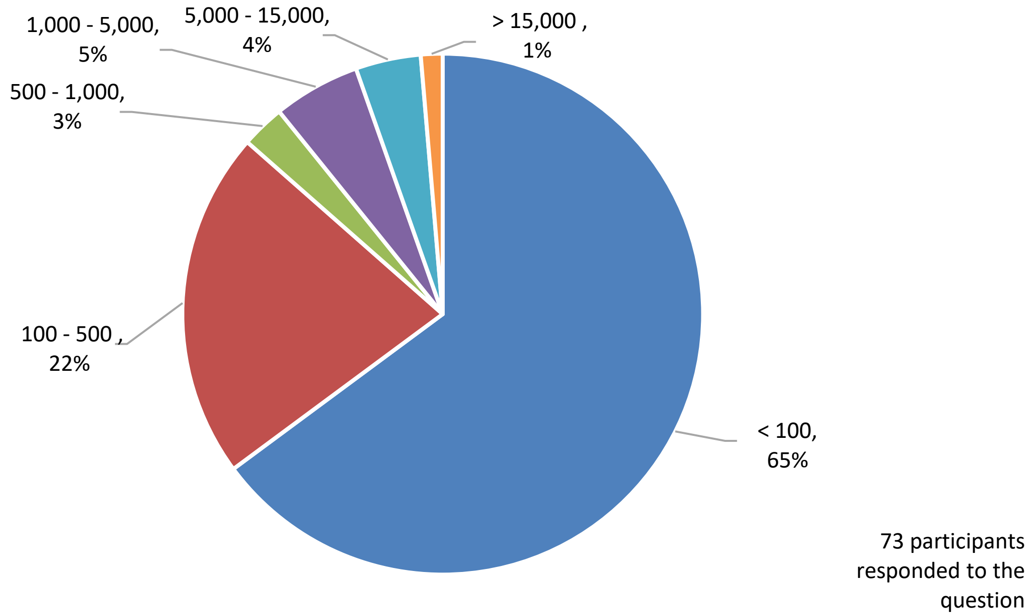

Figure 3-9. Total Number of Permitted Industrial Users Per Utility.

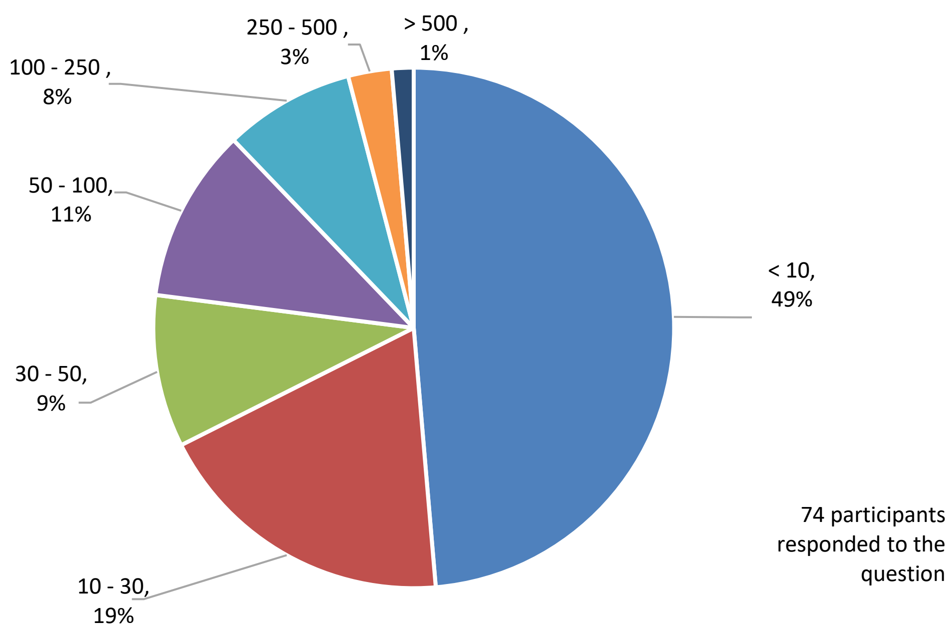

Figure 3-10. Total Number of SIUs Per Utility.

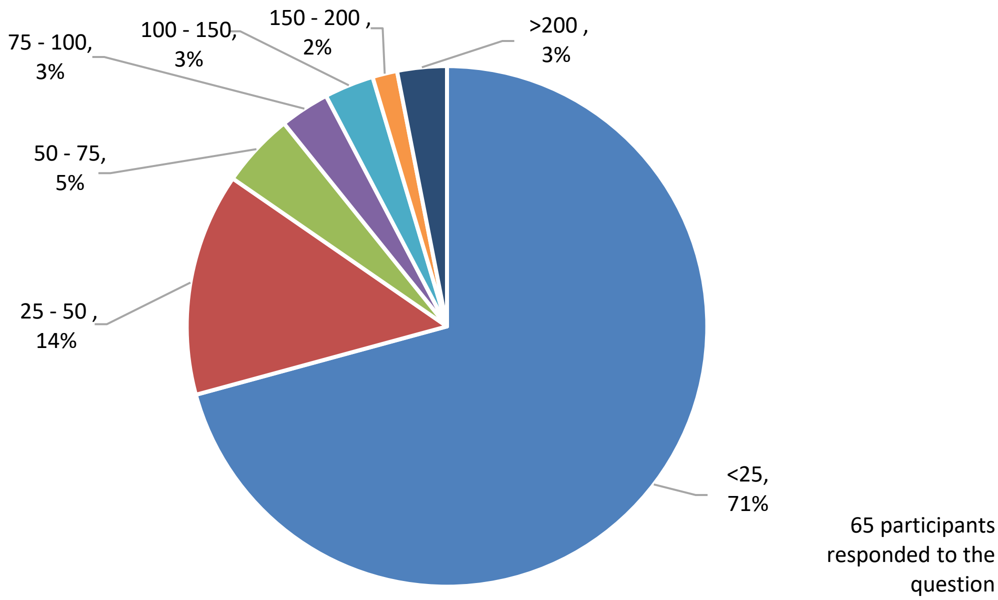

Figure 3-11. Total Number of CIUs Per Utility.

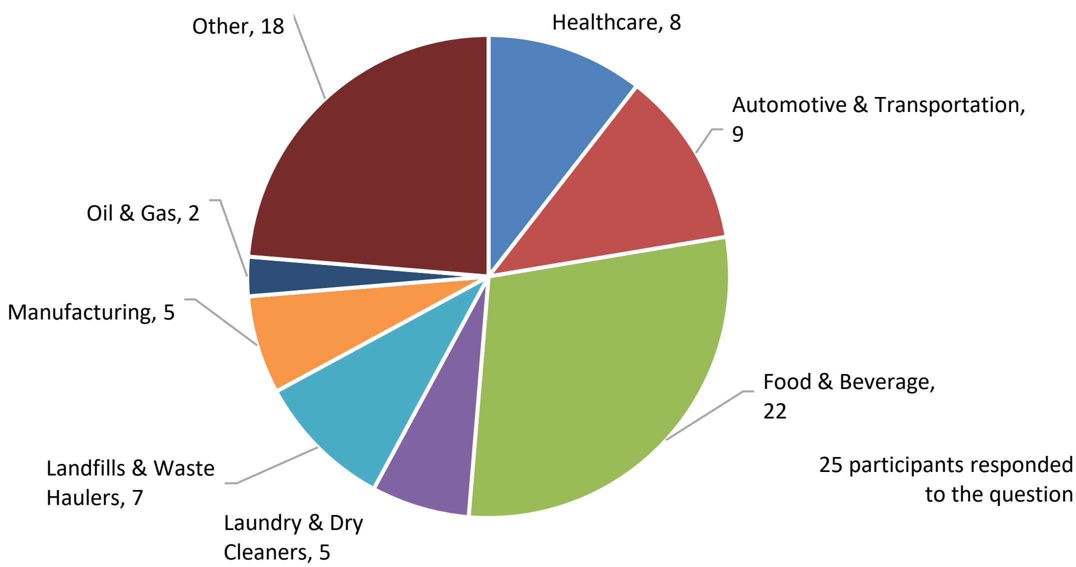

Figure 3-12. Non-Significant and Non-Categorical Permitted Industrial Users.[1]

[1] *Examples of "Other" users include groundwater remediation, fats, oil, and grease, chemical storage and packaging facilities, military installations, embalming facilities, laboratories, silver users, general commercial facilities, commissaries, and fracking facilities.*

Table 3-1 details the distribution of permitted SIUs and CIUs per utility. Of the 73 responding utilities, 37 percent indicated that they only permit the SIUs that are explicitly required by the NPP based on volume or category. Thus, 63 percent of utilities have identified industrial dischargers that are permitted due to the potential to negatively impact the WWTP or AWTP performance. Table 3-1 also shows that on average across all utilities, 64 percent of permitted industries are SIUs and 38 percent are CIUs. Figure 3-13 shows similar information to Table 3-1 by showing the percent of permitted industries that are SIUs and CIUs for each individual utility. There is a wide variation in how utilities approach permitted industries, as shown on Figure 3-13. While 37 percent of utilities only permit SIUs, there are almost 10 utilities where SIUs make up less than 10 percent of permitted industries, meaning the utility establishes permits for a much wider range of industries.

Table 3-1. Prevalence of Significant and Categorical Permitted Industrial Users.

Percent of Utilities that Only Permit SIUs	37%
Average Percent of Permitted Industries that are SIUs	64%
Average Percent of Permitted Industries that are CIUs	38%

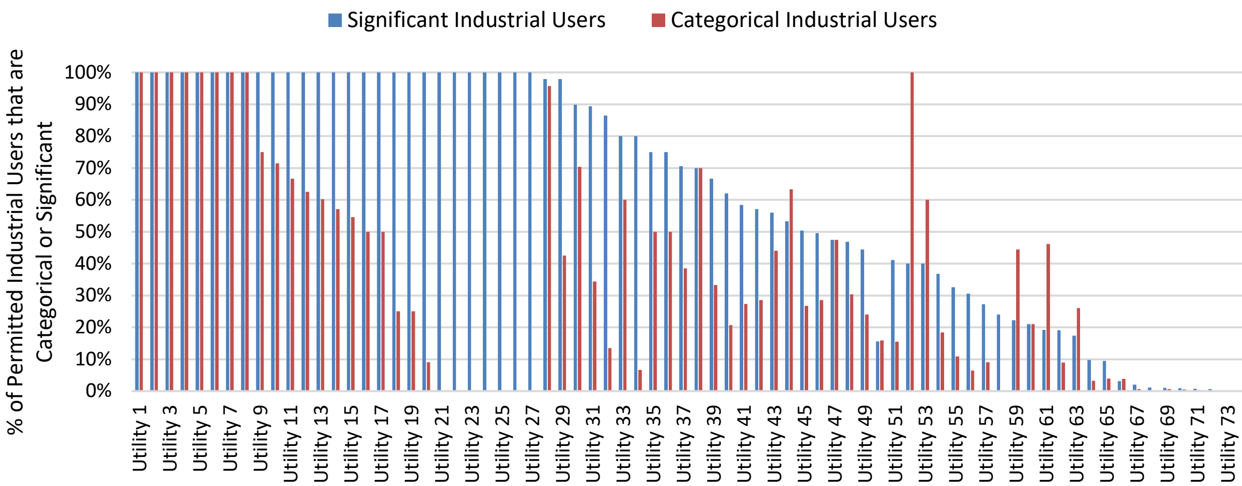

Figure 3-13. Permitted SIUs and CIUs.

The total combined average permitted flow from all industrial users across all survey participants was approximately 490 mgd. Total industrial user flows for each utility are shown on Figure 3-14. Three utilities account for more than 50 percent of the industrial flow across all surveyed utilities. Figure 3-15 shows the ratio between the average industrial user flow and the monthly average plant flow. The median value was 2.75 percent, with one utility as high as 43 percent. Most utilities had a ratio of less than 10 percent, showing that residential and non-permit-requiring commercial flows typically dominate the influent flow profile for utilities.

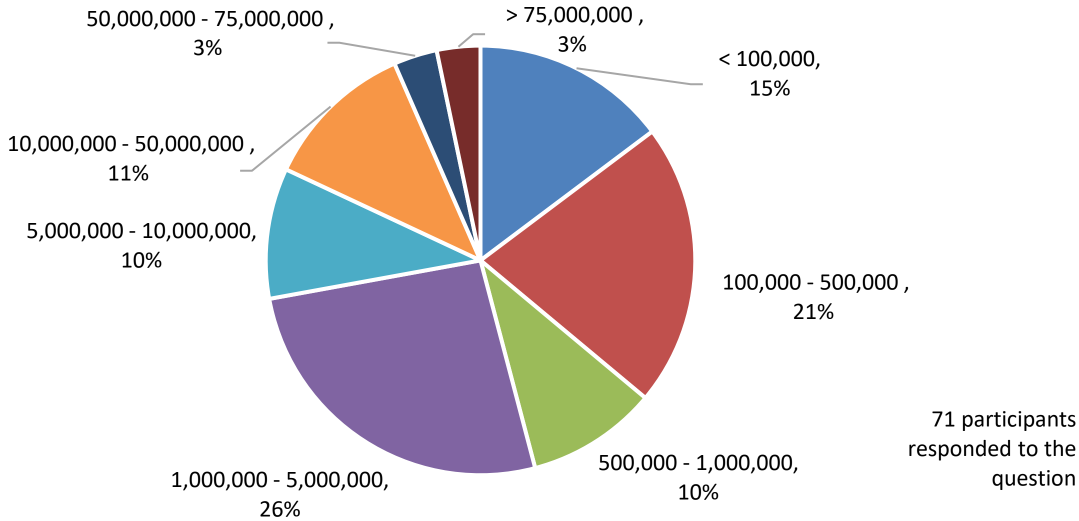

Figure 3-14. Total Permitted Industrial User Flows Per Utility (GPD).

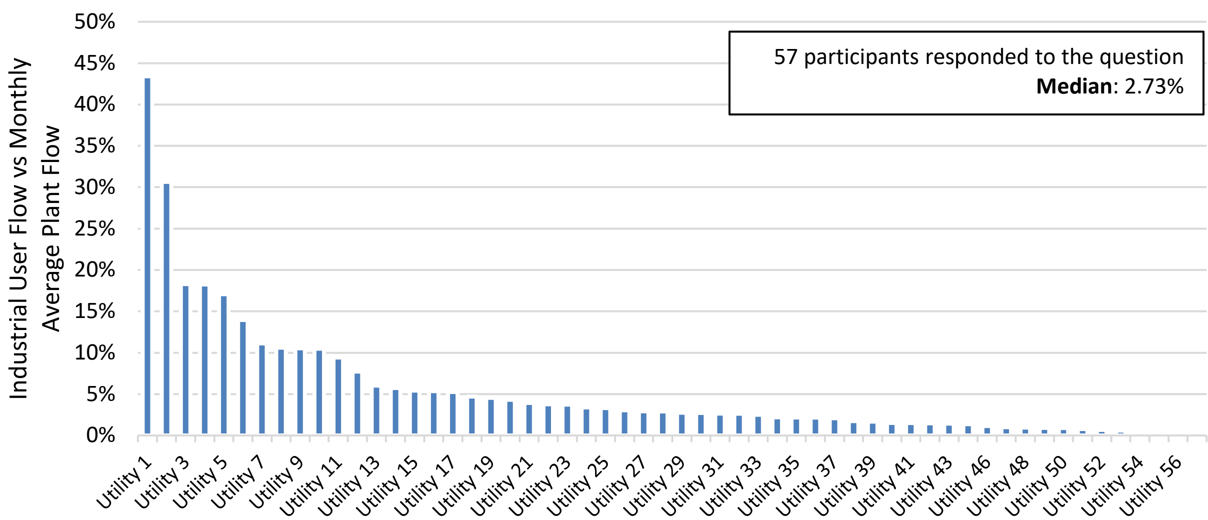

Figure 3-15. Relationship Between Industrial User Flow and Monthly Average Plant Flow Per Utility.

3.3.2 Industry Categories

A series of questions focused on the types of industries (or industrial categories as defined by the EPA) that contribute flow and cause challenges for the surveyed utilities. Figure 3-16 shows the number of utilities (out of the 73 that responded to the question) that have permits for each industrial category. The survey did not ask the utilities to provide the number of permits for each category.

Metal finishing, molding, and casting facilities were the most common type of industry across the participating utilities, with 59 of 73 utilities having permits for that category. Food processing was the second most common, followed by landfills. Forty-five percent of participating utilities have landfills contributing landfill leachate to their collection systems. In addition to the results shown on Figure 3-16, 33 utilities responded they have permits for industrial categories not represented by the listed categories. Some of the other industries include ship repair facilities (1), military installations (1), light manufacturing facilities (1), semiconductors (3), steam electric (2), animal feed (1), water treatment plants (1), inorganic chemical manufacturers (2), corrections institutes (2), soap and detergent manufacturers (1), petroleum refineries (1), electrical component manufacturers (1), construction dewatering (1), electroplating (1), and industrial or commercial laundries (4).

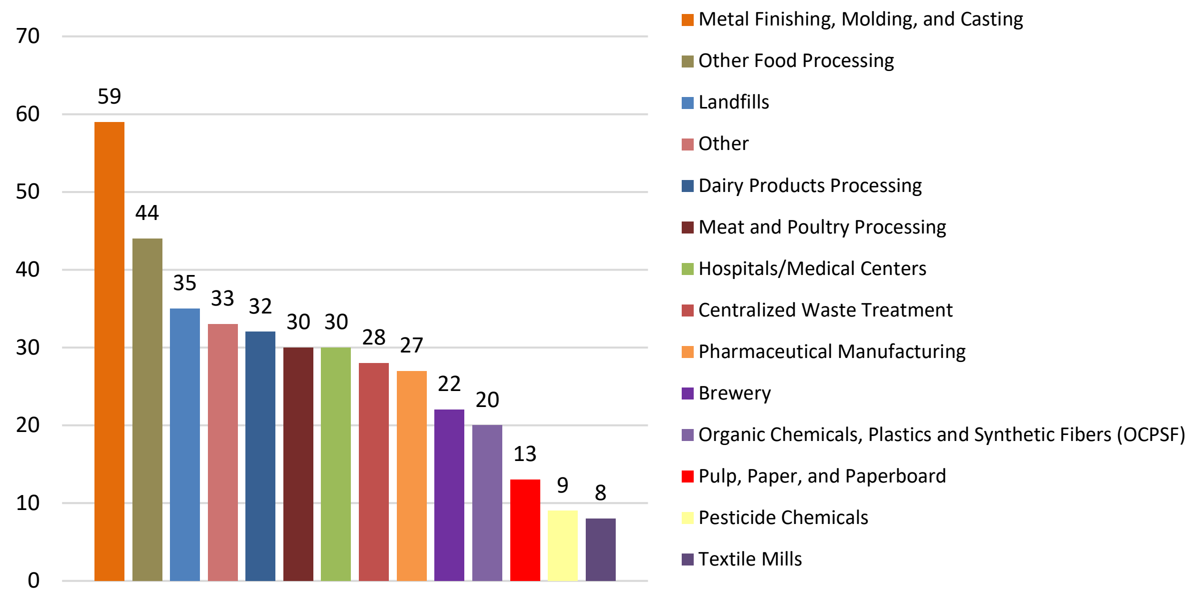

Figure 3-16. The Types of Industries Included as Permitted Industrial Users.
Other food processing does not include meat and poultry products, or dairy products processing.

Figure 3-16 shows the number of utilities that have permitted industries in a variety of categories. Table 3-2 evaluates which industries skew toward larger or smaller utilities, as measured by the total WWTP capacity. Each industry category was compared against the 15 utilities with the highest design average monthly flow and the 15 utilities with the lowest design average monthly flow. As an example, 12 out of 15 of the utilities with the highest flow have permitted landfills, compared to only 2 out of 15 of the utilities with the lowest flow. Table 3-2 suggests that many industrial categories, including food processing, landfills, hospitals, dairy products, meat and poultry products, CWTs, pharmaceutical manufacturing, and OCPSF, tend to be in collection systems for larger utilities more often than smaller utilities.

Table 3-2. Prevalence of Permitted Industrial Users for Larger and Smaller Utilities.

	Percentage of Utilities That Have Permitted Industries in Each Category		
	Out of the 15 Utilities with the Highest Flow	Out of All Participating Utilities	Out of the 15 Utilities with the Lowest Flow
Metal Finishing, Molding, and Casting	93%	80%	73%
Other Food Processing	80%	59%	27%
Landfills	80%	47%	13%
Hospitals/Medical Centers	53%	41%	13%
Dairy Products Processing	67%	43%	7%
Meat and Poultry Products	67%	41%	7%
Centralized Waste Treatment	93%	38%	7%
Pharmaceutical Manufacturing	73%	36%	7%
OCPSF	73%	27%	13%
Brewery	27%	30%	13%
Pulp, Paper, and Paperboard	27%	18%	13%
Pesticide Chemicals	40%	12%	0%
Textile Mills	20%	11%	13%

Participants were asked to identify the industrial categories that present the biggest challenge to their utility. The question was asked open-ended to utilities, so the challenge could be for water quality (wastewater or potable reuse, or other), operations, or other reasons. Figure 3-17 shows the results. Some utilities selected multiple categories. Metal finishing, molding, and casting facilities and centralized waste treatment (CWT) facilities were the most listed challenges of the industrial categories. CWT facilities accept diverse waste streams and discharge to POTWs. There are four categories of CWTs: oily wastes, organic wastes, metals wastes, and combined wastes.

Of the 59 utilities that answered that they have metal finishing, molding, and casting facilities, 19 of them (32 percent) said that they presented the biggest challenge. Three of the eight potable reuse utilities identified this as their most challenging industrial user. Some participants indicated that this industry is known to discharge heavy metals that negatively impact biosolids programs, particularly for land application. Other utilities noted that this industry was particularly challenging due to their frequent violations and the additional resources required to monitor their discharge and ensure compliance. One utility explained that these facilities often use contaminants that are particularly challenging to monitor or treat when practicing DPR and gave PFAS as an example. Another found that the chemical byproducts found in their discharge can lead to exceedances for total toxic organics.

Of the 28 utilities that answered that they have CWT facilities, 18 of them (64 percent) said that CWTs present the biggest challenge. Four of the eight potable reuse utilities identified CWTs as their most challenging industrial discharger. CWT facilities are known to be challenging for utilities due to the intermittent and inconsistent nature of the flows and the challenging water quality of waste requiring a CWT for discharge. One utility found that CWTs can create highly concentrated discharges that led to slugs of atypical contaminants. In many cases, those highly concentrated contaminants are discharged in a quantity so small that they become very difficult to detect when mixed with other discharges, making them even harder to treat. Other utilities indicated that the waste producer is periodically misidentified, either intentionally or not, creating additional treatment challenges.

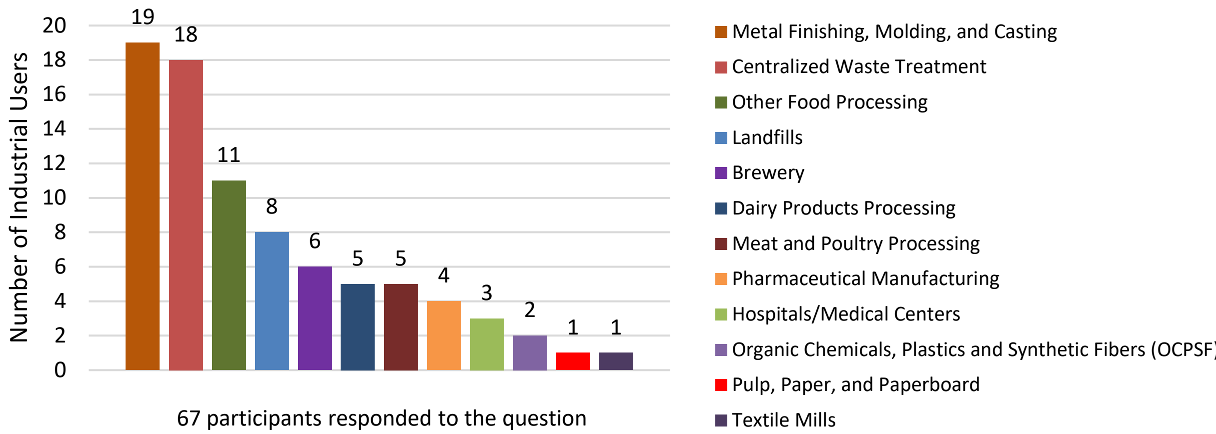

Figure 3-17. The Categories of Industrial Users that Present the Biggest Challenge to Utilities.

Twenty-four utilities (out of 71) indicated they have an industry that contributes at least 5 percent of the total flow to a single WWTP. This amount of flow presents a significant influent load to the WWTP and industries with this high of flow are often the first to focus on for ESCPs. Figure 3-18 shows the number and type of industries that contribute at least 5 percent to the WWTP flows. Food processing received the highest response, followed by breweries, dairy products, and pulp, paper, and paperboard.

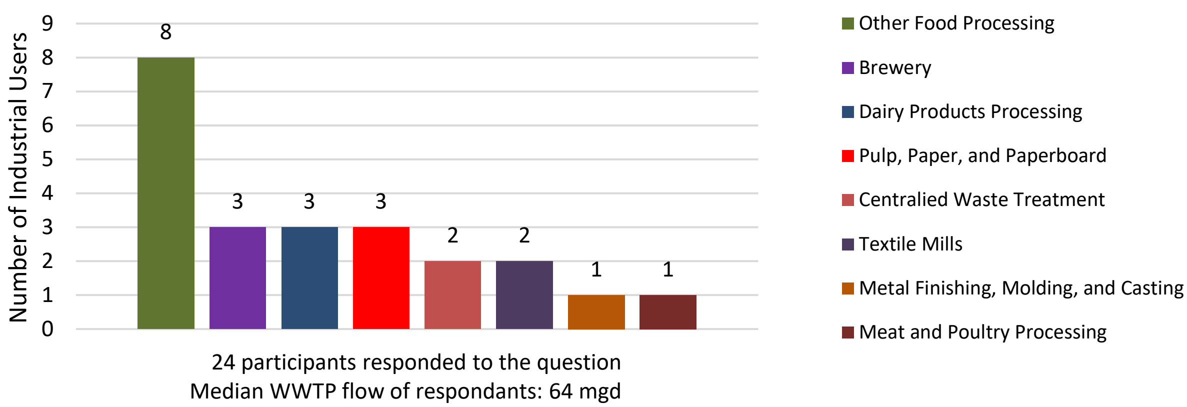

Figure 3-18. Number of Utilities that Have a Single Industrial User that Contributes at Least 5% of the WWTP Flow.

3.3.3 Challenging Industrial Contaminants

Figure 3-19 shows the types of contaminants that present the biggest challenge to the participating utilities. This question asked the utilities to identify the contaminants that pose the biggest challenge for operations without specifying potable reuse, One Water, or any other program. Metals were the most common category listed, with copper, molybdenum, nickel, and mercury specified most frequently. This aligns with the findings from Figure 3-19, which identified metal finishing, molding, and casting facilities as the type of industrial user presenting the biggest challenge to utilities. Fats, oils, and grease (FOG) also had a high number of responses as these contaminants are known to cause blockages in collection systems and can be difficult to biologically degrade during treatment. Bulk organics, most commonly biochemical oxygen demand (BOD), and trace organics, consisting of a wide array of specific contaminants that include PFAS, 1,4-dioxane, PCBs, and microplastics, among others, were also frequently identified as a challenge to utilities.

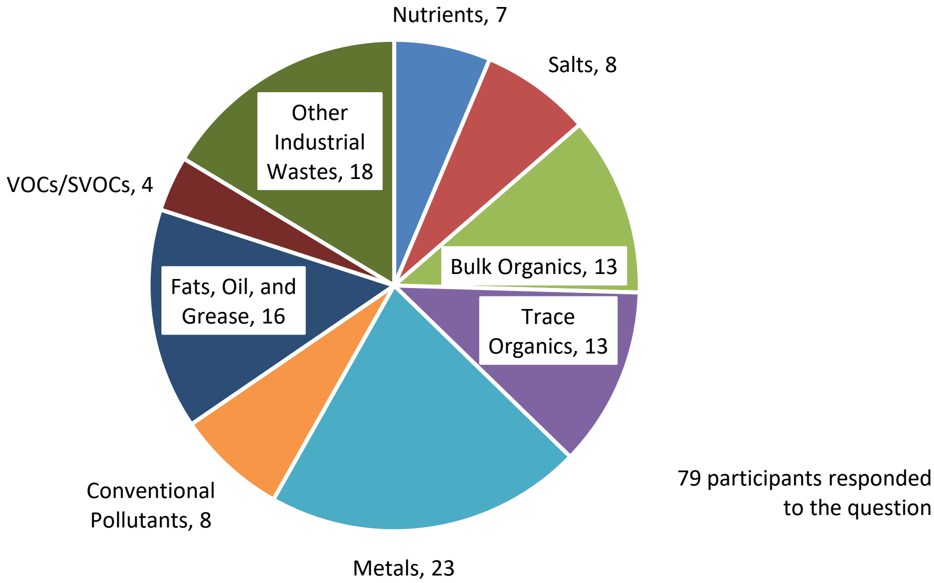

Figure 3-19. Types of Contaminants that Present the Biggest Challenge to Utilities.

3.3.4 Permitting and Limits

Of the participating utilities, 64 percent have created more stringent standards than the NPP requirements (i.e., site-specific or local limits) to combat specific contaminants. Note that this question did not apply to the two utilities not in the United States that responded to the survey. Figure 3-20 shows how the more stringent standards were applied across industries. In most cases (42 out of 60), the site-specific limits were applied to all permitted industrial users instead of a specific industry or a subset of industries. Eighteen percent of utilities (11 out of 60) responded that local limits are applied to specific industries based on their specific load contribution to the WWTP.

As more utilities implement potable reuse programs, they may look to set site-specific limits for individual industries that provide a significant influent load for specific contaminant(s) that are challenging for advanced treatment. To do so, it will require the utility to perform sampling campaigns at each individual industry to characterize the sources of the various influent contaminant loads. Setting site-specific limits is recommended for potable reuse to avoid setting limits for all permitted industries when the majority of the industries do not discharge a meaningful amount of the contaminant, thereby setting an undue sampling burden on those industries. HRSD provides a relevant example of a site-specific limit developed for acrylamide. Their approach and the outcome are detailed in their case study in Chapter 4.

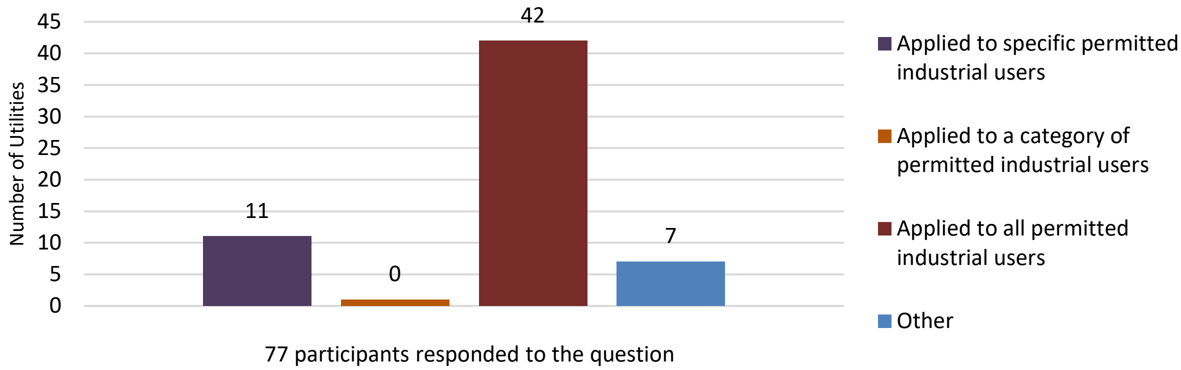

Figure 3-20. Application of More Stringent Standards to Industrial Users.

Of the 68 utilities that participate in One Water initiatives, 21 percent indicated they have developed limits in support of those programs. Figure 3-21 shows the contaminants included in those local limits and how many utilities have applied them. Metals were the most common type of contaminant to have local limits applied in support of One Water initiatives. Interestingly, no PFAS were identified with a limit applied; it is expected that as regulations progress, more utilities will implement PFAS limits.

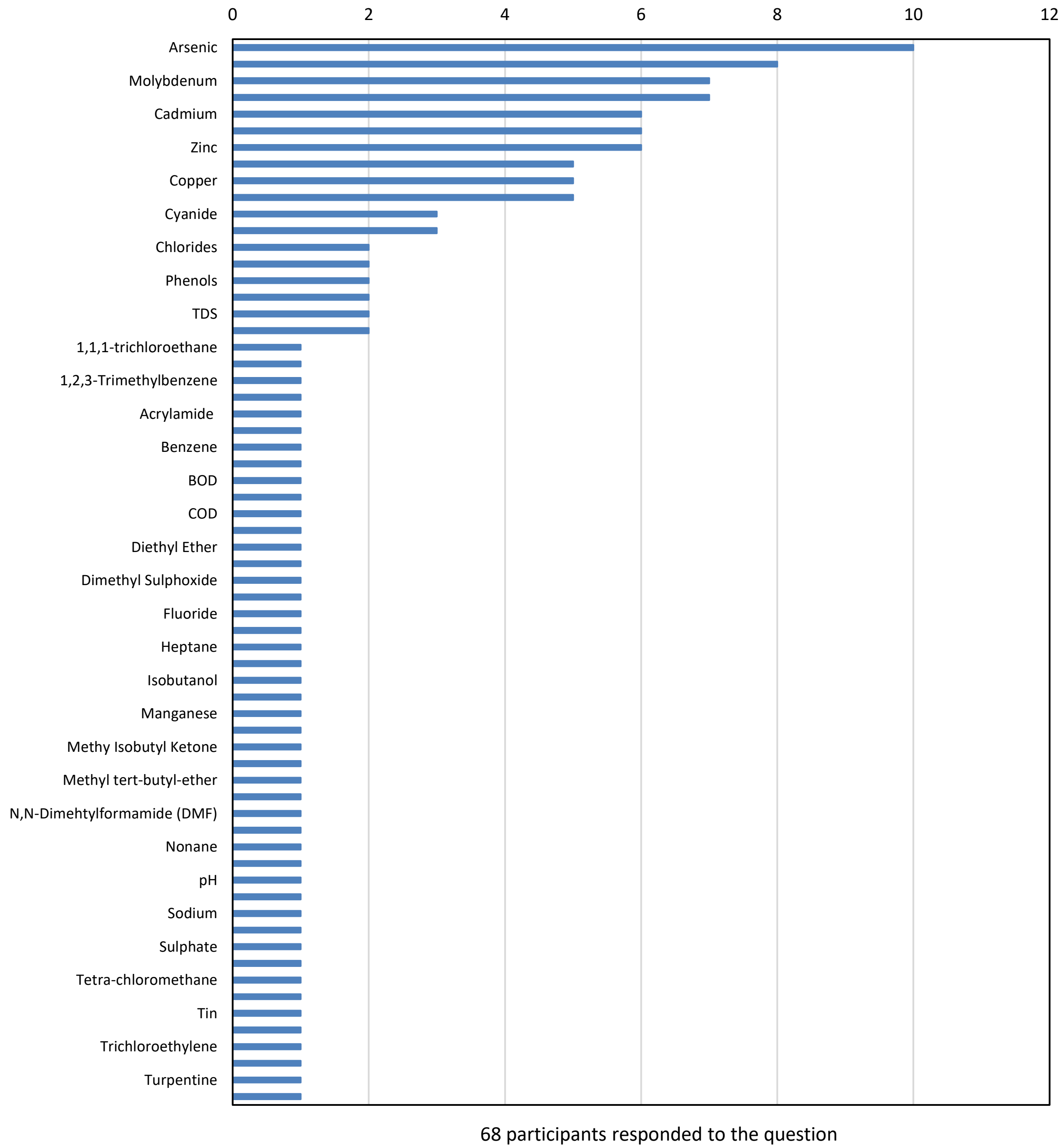

Figure 3-21. Contaminants that Had Site-Specific or Local Limits Applied Due to One Water Initiatives.

3.3.5 Pretreatment Program Characteristics

This series of questions focused on the implementation of different aspects of each utility's pretreatment program. These questions tend to be more qualitative but do provide insight on what is and is not common among utilities. Figure 3-22 shows the minimum frequency of inspections (utility visiting the industry to inspect the industrial process and waste discharge). Figure 3-23 shows the minimum frequency of sampling (either by utility staff or industry self-sampling). Note that semiannually sampling takes place twice per year, and biweekly sampling takes place every 2 weeks. Both inspection and sampling occur most commonly on an annual basis. Some utilities indicated that sampling frequency varies per industrial user depending on the nature of the discharge water. For example, one utility indicated that CWT facilities are sampled on a quarterly basis, whereas other industrial users are typically sampled twice a year.

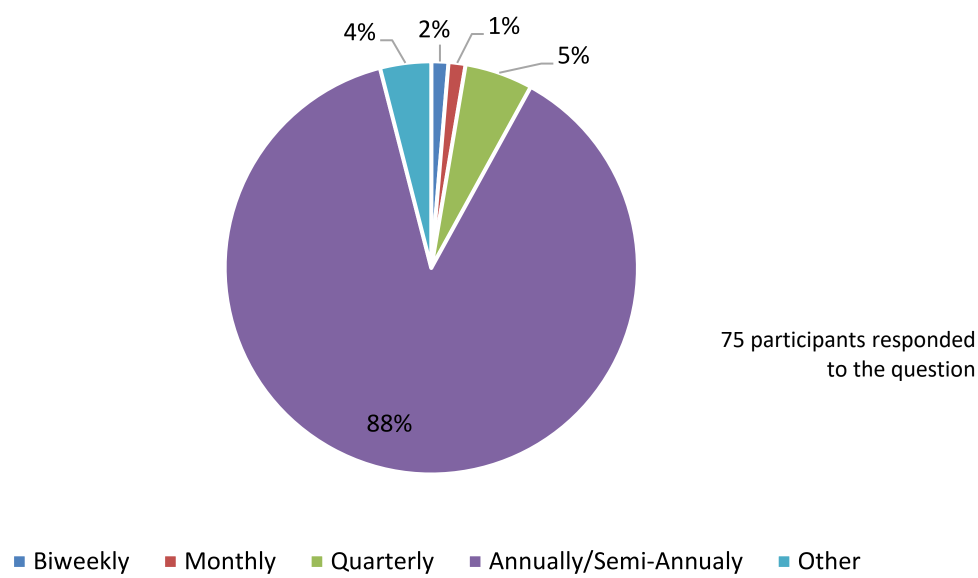

Figure 3-22. Minimum Frequency of Inspection at Industrial Users.

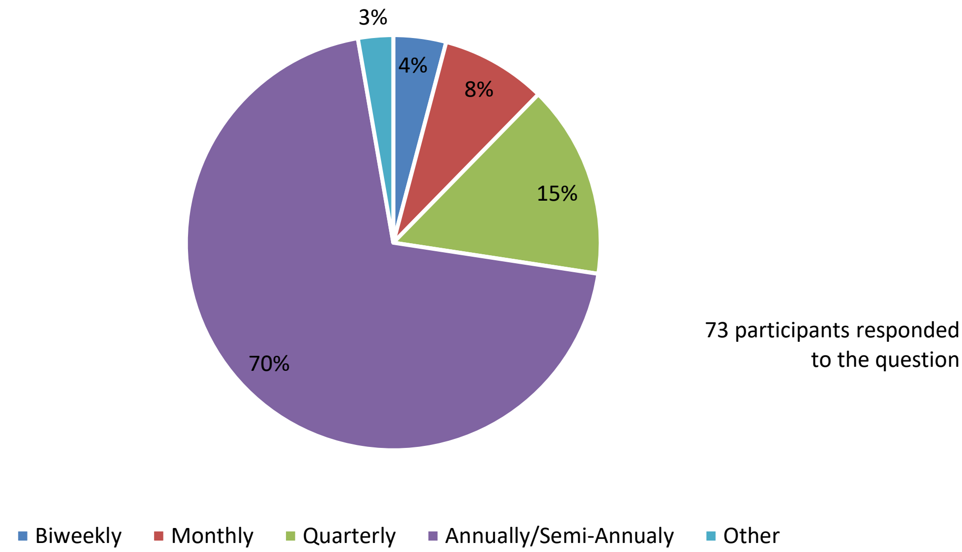

Figure 3-23. Minimum Frequency of Sampling at Industrial Users.

Figure 3-24 shows the efforts utilities have included in their pretreatment program to better manage the challenges they face. This figure shows the answers to seven different yes/no questions. The blue bars on Figure 3-24 show how all utilities answered while the red dotted bars show how the utilities that currently practice potable reuse answered. A quick summary of the responses to each question is provided here for context:

- More than 80 percent of the utilities require industries to perform their own sampling to offset staff time for sampling. This does not imply that a utility does not sample itself; often, the industry samples are in addition to the utility samples.
- More than 60 percent of utilities take an inventory of all chemicals onsite at each permitted industry. This is particularly important for utilities considering potable reuse. As discussed in Chapter 5, it is recommended that all utilities practicing potable reuse maintain this type of inventory to manage the risk of a chemical spill in the collection system. Knowing most utilities already maintain this type of database is encouraging.
- More than 40 percent of all utilities are concerned about cycling up of total dissolved solids (TDS), and 70 percent of utilities that practice potable reuse are concerned about cycling up of TDS. Cycling up of TDS is important for utilities practicing potable reuse, particularly for those in inland locations where it is difficult to use RO to reduce salinity due to brine management challenges. This topic is discussed further on Figure 3-30.
- Less than 40 percent of all utilities have uniform sampling across all industries. The majority of utilities have programs in place to adjust sampling frequency based on the industry type, flow, or water quality. However, among the utilities that have potable reuse, 80 percent have uniform sampling protocols.
- More than 30 percent of all utilities, and 50 percent of those with potable reuse programs, utilize online monitoring in the collection system. This is a key component of ESCPs and is expected to grow in the future. This topic is discussed further in Section 3.3.7.
- More than 20 percent of utilities recognize or reward industries for good performance. As

potable reuse programs grow, the project team hopes this percentage also grows. Implementing potable reuse can be seen as a challenge to certain industries due to increased regulation. However, if the industries are recognized or incentivized for their good performance and understand the value of the potable reuse programs, they may be more inclined to adhere to their permit requirements. More discussion on this topic is provided later in this chapter.

- Lastly, just more than 10 percent of all utilities have adjusted their industrial pretreatment program for One Water or reuse initiatives. But, intuitively, of those utilities that already have potable reuse programs, 75 percent have adjusted their programs. It is expected as more utilities pursue potable reuse, industrial pretreatment programs will continue to be adjusted.

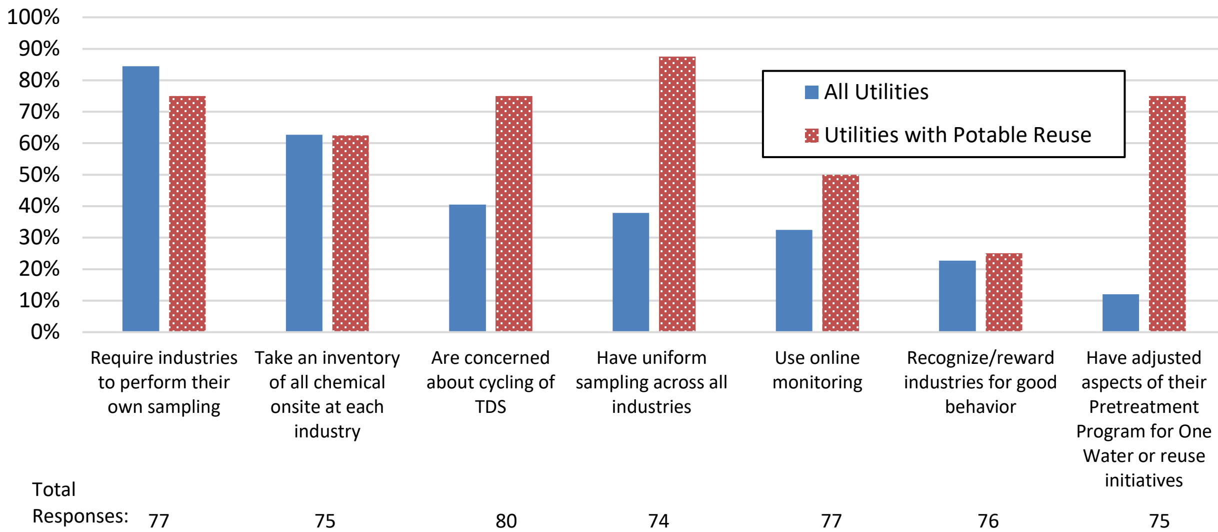

Figure 3-24. Frequency (in %) of Utilities with Various Pretreatment Features.

Utilities were asked to indicate what types of changes they have made for their One Water initiatives or reuse programs. Figure 3-25 shows the responses of the 9 utilities that indicated they have made changes specifically for those reasons (the other 66 utilities that responded to this question stated that this question did not apply to them or that they have not made changes; two utilities selected multiple answers). Additional sampling and monitoring efforts was the most common change made in support of One Water or reuse initiatives.

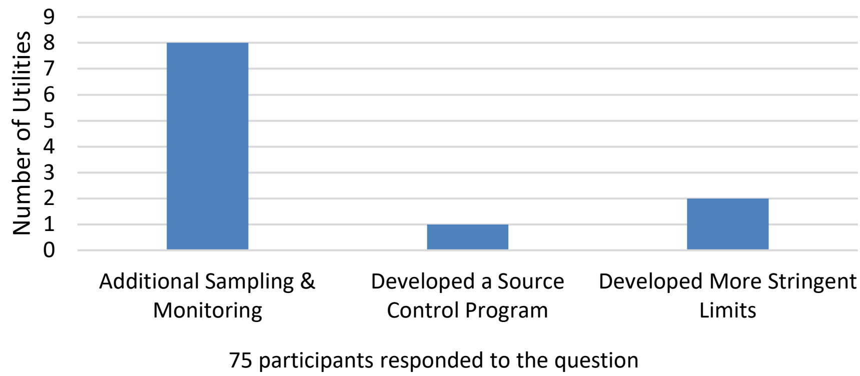

Figure 3-25. Types of Changes that have been Made to Support One Water Programs.

Utilities were asked several questions discussing the various types of responses and courses of action that take place when an industrial user violation occurs. Figure 3-26 shows that there is an almost even split between the number of violations that are self-reported by the industry versus those that are identified by the utility. Multiple utilities indicated that in many cases, both the utility and the industry report the violation. This is encouraging as self-reported violations suggest a desire to adhere to the permit rather than hoping that the violation will go unnoticed. On Figure 3-27, 88 percent of participating utilities indicated that violations typically occur during normal industry operation, as opposed to one-time discharge events (this question was asked to identify if utilities thought that industries purposely discharge contaminants that would result in a violation at times of the day/night when they are hoping to not be caught; it appears that most utilities do not believe this is occurring). Figure 3-28 shows how industries typically respond to violations. Only 5 percent of industrial dischargers respond contentiously to violations or continue operation as normal; the vast majority work with the utility to find a common solution or immediately adjust their operation to comply with the violation. Lastly, Figure 3-29 shows the number of industrial violations that occur in a typical year, with the utilities largely split between answering less than five violations (50 percent of responses) and more than 20 violations (30 percent of responses). Of the 22 utilities that answered “20 or more” violations, 14 of those have a total WWTP capacity greater than 100 mgd. Table 3-3 shows the distribution of violations for the 15 utilities with the highest number of permitted industrial users compared to the 15 utilities with the lowest number of permitted industrial users. The results confirm that more violations occur with utilities that have a higher number of permitted industries.

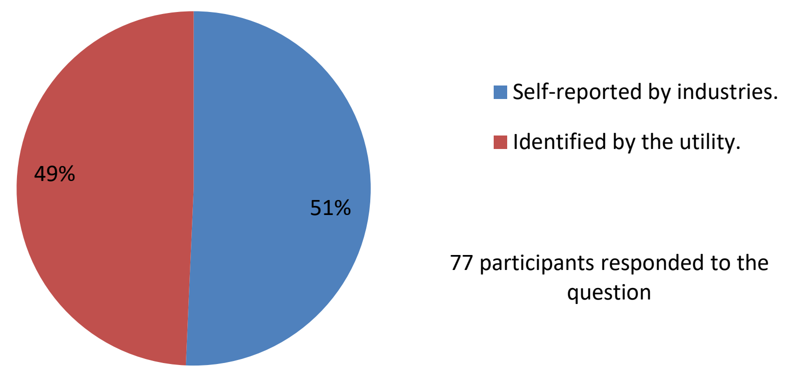

Figure 3-26. Typical Reporting of Violations.

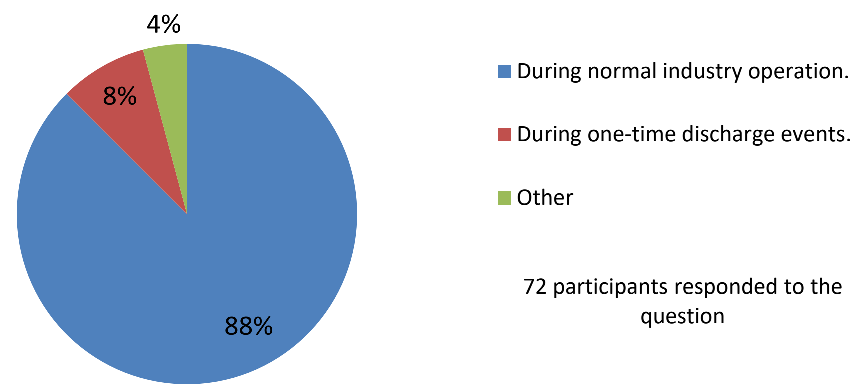

Figure 3-27. Typical Occurrence of Violations.

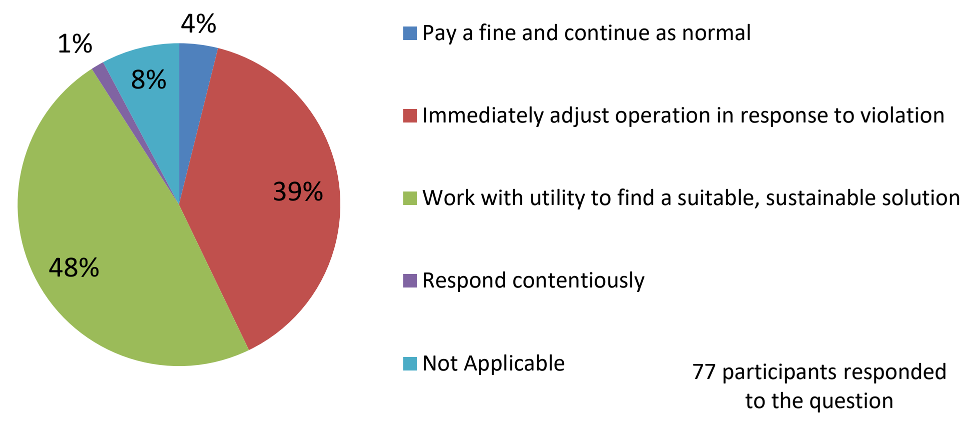

Figure 3-28. Typical Response to Violations.

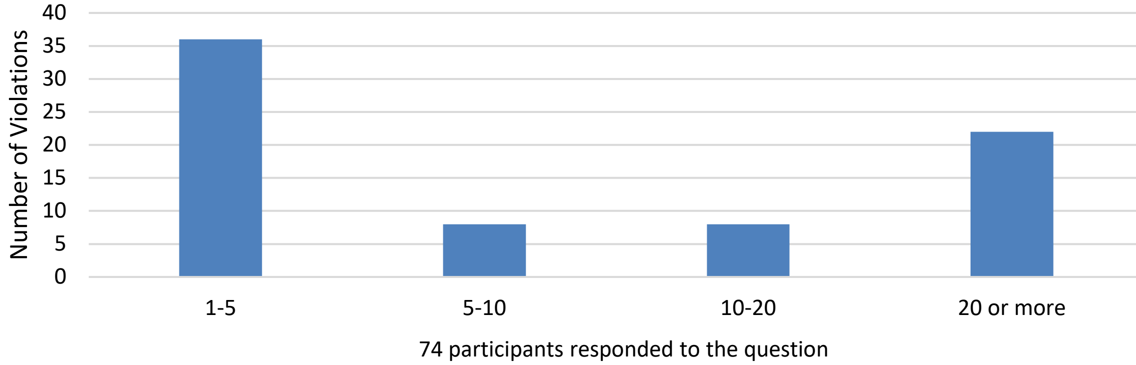

Figure 3-29. Number of Industrial Discharge Violations During a Typical Year.

Table 3-3. Industrial Discharge Violations Compared to Number of Permitted Industrial Dischargers.

Number of Industrial Discharge Violations During a Typical Year	% Of the 15 Utilities with Highest Number of Permitted Industrial Users	% Of the 15 Utilities with the Lowest Number of Permitted Industrial Users
1 to 5	20%	80%
5 to 10	7%	7%
10 to 20	13%	7%
20 or more	60%	7%

High concentrations of salts found in industrial wastewater can limit the potential for reuse initiatives because the domestic wastewater cycle typically increases TDS by around 200 mg/L (Thompson 2006). Thus, the more water is reused, the higher the salinity will climb unless salt is removed using RO or other treatment technologies. Forty-six of the participating utilities indicated they sample for TDS, sodium, magnesium, calcium, chloride, and/or sulfate at their WWTPs or industries. Thirty-three utilities indicated they are concerned about increasing salt concentration in the watershed due to conservation, reuse, or other drivers. Not surprisingly, of the utilities that are concerned about salt concentrations in the watershed, 71 percent sample for these parameters at their WWTPs or industrial users, as shown in Figure 3-30.

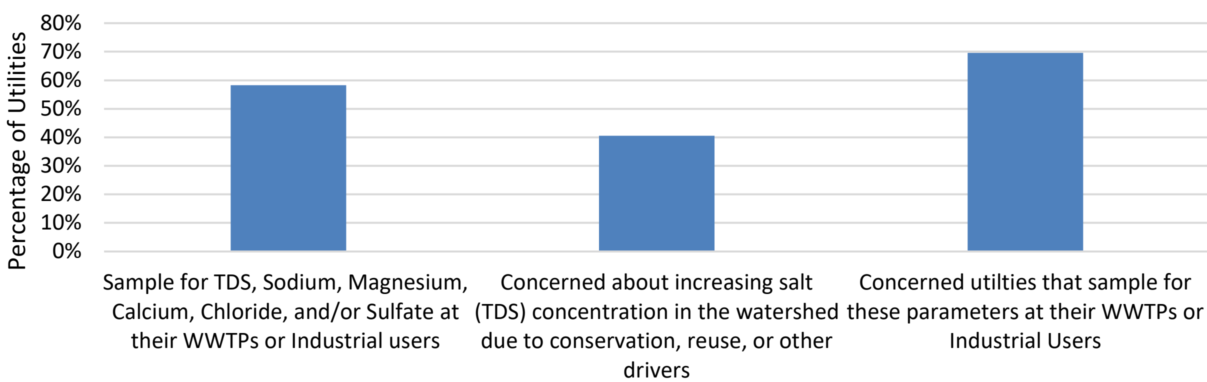

Figure 3-30. Utility Responses to Salt Concentration in the Watershed.

Utilities were asked to characterize their relationship with industrial users, as shown in Figure 3-31. More than 80 percent of utilities responded that they have collaborative, educational, and/or transparent relationships with their industrial users. This is particularly important to the project team as this collaboration by all stakeholders that contribute to the water cycle is essential to the success of potable reuse projects. Following Figure 3-31 are a series of bullet points that highlight how different utilities perform this recognition. The project team would like to highlight these examples and encourage other utilities to set up similar programs.

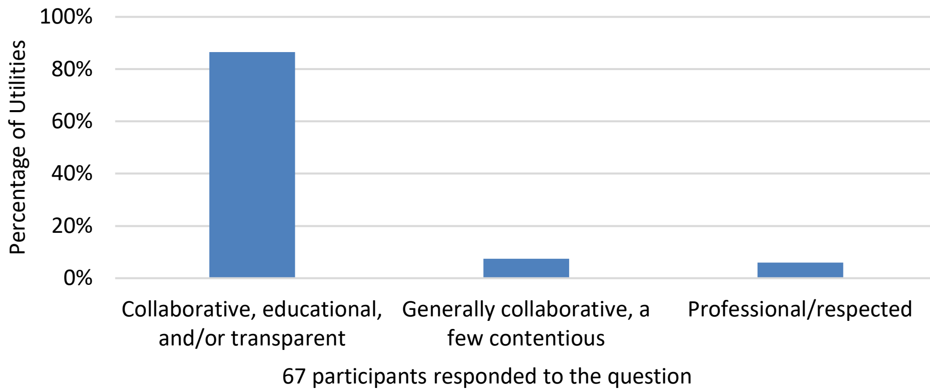

Figure 3-31. How Utilities Characterize their Relationships with Industrial Users.

- Hampton Roads Sanitation District: operates an awards program to recognize the industries that achieve perfect compliance. If a utility goes an entire calendar year with no violations, they earn a Gold award. Five years of perfect compliance earns a Platinum award, and ten years of perfect compliance earns a Diamond status. The awards are often distributed at a luncheon and a press release or newspaper advertisement is also published noting all award winners. Additionally, any permitted industrial user can submit an application that highlights a project where they have achieved pollution reduction to be acknowledged for pollution prevention.
- City of Santa Cruz: uses incentive programs that focus on three main tactics – awards, public events, and publications. Industries that demonstrate consistent compliance over multiple years are recognized at an annual awards dinner. At this event they are spotlighted on television, receive engraved plaques, and have an opportunity to speak to the public about their program and their successful compliance methods. Additionally, the Clean Ocean Business is built upon recognizing local businesses that continuously comply with the utility's Best Management Practices (BMPs), which are designed to assist them in maintaining environmental integrity. Qualifying businesses are recognized in publications and major newspapers in the community.
- Metropolitan Water Reclamation District of Greater Chicago: maintains a list of SIUs that do not have any violations in a year. These industries are highlighted as "Exceptional Compliance" users on their website. This list is also published in the local newspapers.
- Trinity River Authority of Texas: industries are regularly reviewed to determine an appropriate monitoring frequency. The monitoring frequency is based on how close the sampling data is to the limit for a given parameter. This information is used to reduce sampling frequencies for industries that are consistently below their permitted limits, which incentivizes compliance.
- Jacksonville Energy Authority (JEA): uses an awards program similar to HRSD. Industries are

awarded Silver, Gold, and Platinum awards for their many years of compliance. These awards are distributed at an annual ceremony with local media coverage.

- LACSD: awards certificates of recognition for compliance and congratulatory letters to the industrial users that expend a considerable effort to meet the regulations of the Sanitation Districts and the EPA. These industrial users must receive no notices of violation in a year, which would include violating effluent limits, permit requirements, or financial obligations to the Sanitation Districts.
- Massachusetts Water Resources Authority (MWRA): distributes an annual monitoring charge that consists of two primary parts – a permitting charge and monitoring charge. Points are assigned to users with violations, and the points influence the monitoring charge. Less violations result in a lower monitoring charge.
- King County Wastewater Treatment Division: offers an awards program similar to HRSD and JEA. Industries are acknowledged for their dedication to protecting public health, the environment, and wastewater infrastructure by maintaining compliance with their discharge permits. After multiple years of compliance, industries are awarded Silver or Gold awards. Award recipients are acknowledged on their website.

3.3.6 Effects on WWTP Operation

Utilities were asked about the effect of industrial violations on WWTP operation. Figure 3-32 shows that the vast majority of utilities (62 out of 77) responded that there were three or less occasions in the past three years where the WWTP experienced challenges due to influent slugs from the collection system. This suggests that many of the industrial violations do not lead to WWTP performance challenges. Eight of 77 utilities that responded participate in potable reuse. Five of those eight also indicated there were three or less occasions in the past three years where the WWTP experienced challenges due to slugs. This is encouraging for the implementation of potable reuse as WWTP upsets can make it difficult to meet advanced treatment water quality requirements.

The utilities that indicated they experienced performance challenges as a result of influent slugs were asked to elaborate on the incidents and their approach to identifying the source(s). In most cases, the slugs came from small-volume, high-strength, one-off discharges that can be difficult to monitor or predict. Some utilities noted performance challenges when an industrial user experienced a failure in an onsite treatment system (i.e., pH buffering). This suggests that redundancy is important for the pretreatment equipment used by industries.

Utilities indicated that identifying the specific cause of the slug can be very difficult but monitoring and sampling in their collection system has been the most helpful in identify the responsible industrial user. Responsible parties are more frequently identified when there is a sustained discharge. Some utilities have found success correlating the timing of slugs with known discharge events for the industrial users that have infrequent discharges. Most utilities noted that increased pretreatment resources, process monitoring, and maintenance were all effective preventive measures to reduce the impacts and occurrences of slugs. Additionally, maintaining a good relationship with industrial users who tend to have intermittent discharges or problematic water qualities can be helpful when managing performance challenges by allowing utilities to predict influent slugs.

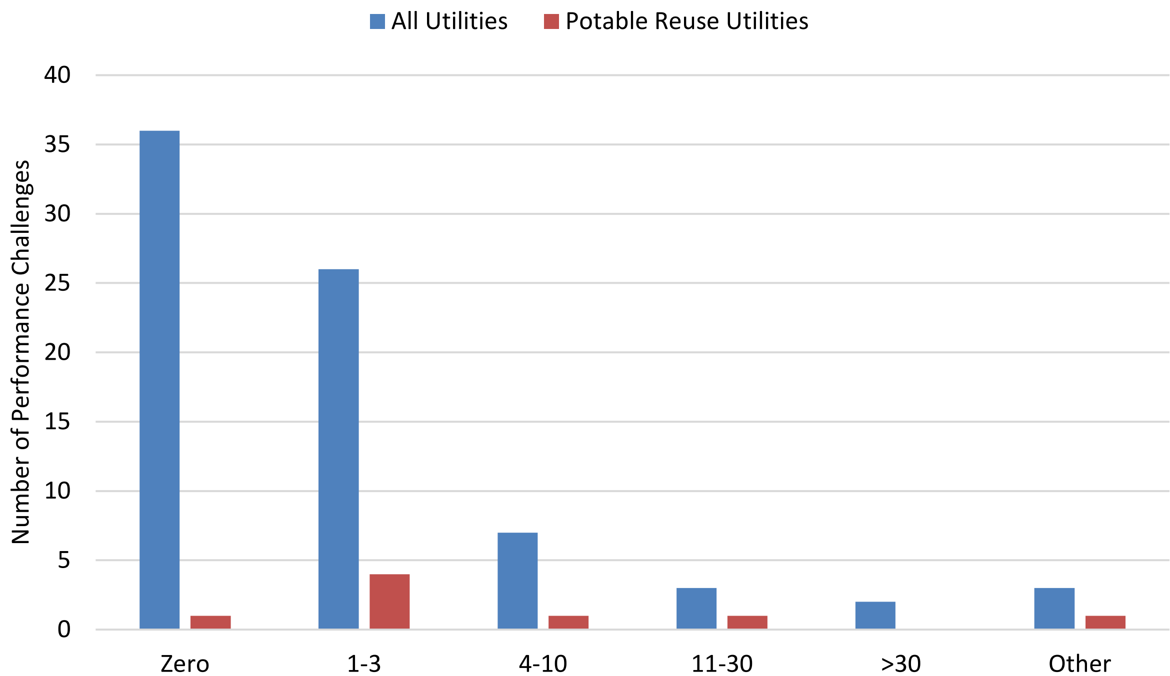

Figure 3-32. Number of Times in the Past 3 years a WWTP Experienced Performance Challenges Due to Influent Slugs from the Collection System.

Of the participating utilities, 23 indicated they have identified contaminants that impact their treatment performance (not specific to reuse or One Water). The types of contaminants identified, and their respective frequencies, are shown in Figure 3-33. Metals were most commonly identified, similar to Figure 3-21 above, but PFAS and 1,4-dioxane also received responses.

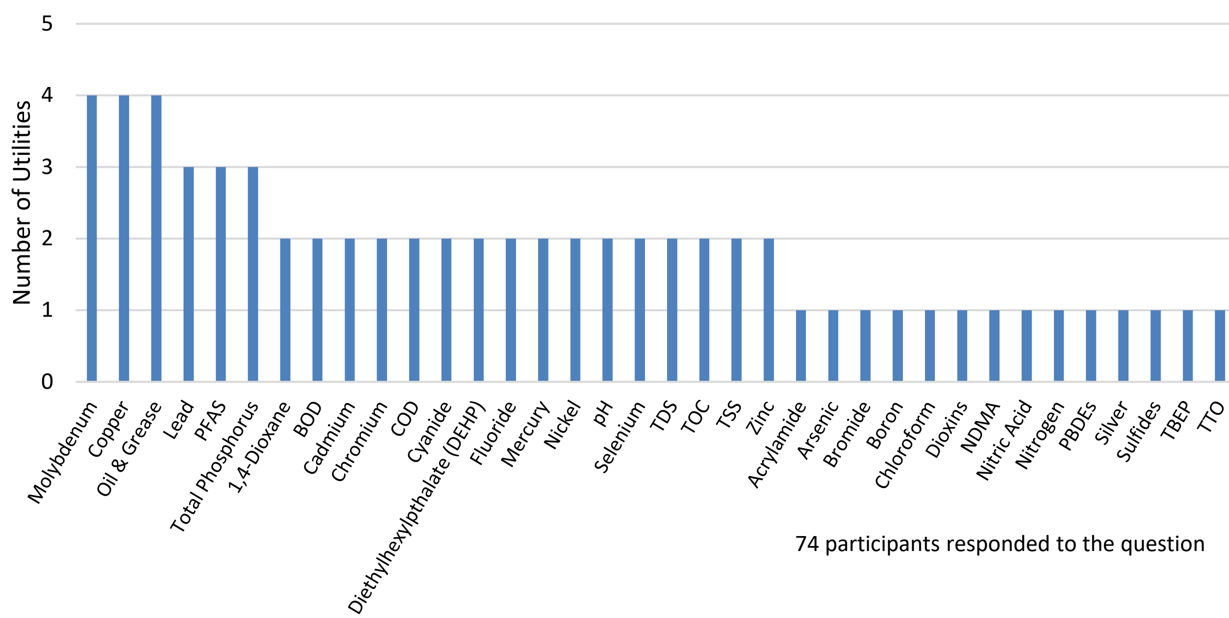

Figure 3-33. Number of Participants Identifying Contaminants that Impact Treatment Performance.

Figure 3-34 shows the relative frequency of contaminants that were indicated as challenging contaminants for utilities. Several utilities identified molybdenum (byproduct of metals finishing and often found in fertilizers) as a contaminant that presents challenges to their treatment processes, and in some cases had specific local limits applied to it. Those utilities were asked to explain how molybdenum impacts their treatment performance and any One Water or reuse initiatives they may have. Four utilities explained that molybdenum is primarily a challenge with biosolids reuse and disposal. When biosolids exceed limits for molybdenum, the number of alternative applications and disposal options decreases. For example, one utility indicated they are required to meet very stringent standards for land applied biosolids.

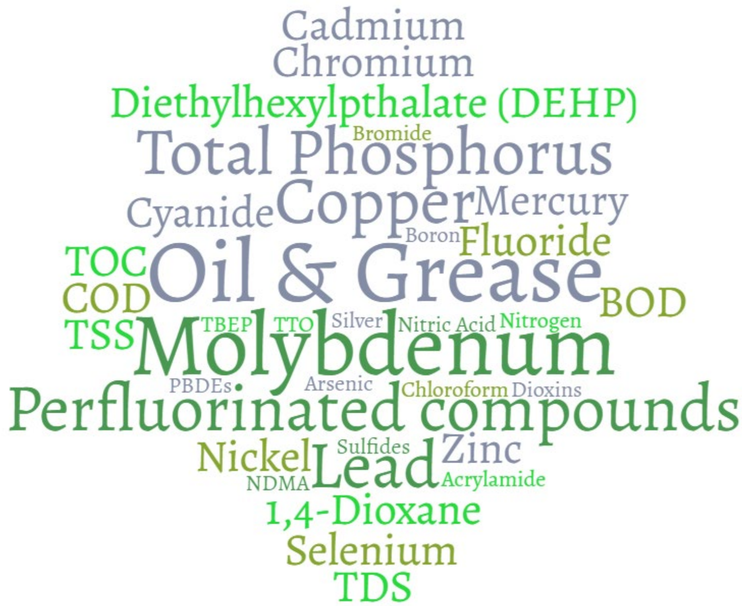

Figure 3-34. Relative Frequency of Contaminants that Impact Treatment Performance.

3.3.7 Online Monitoring

More than 30 percent of participating utilities indicated they use online monitoring in the collection system. Of those utilities, 55 percent indicated they use their online monitoring to identify industries responsible for upsets, as shown in Figure 3-35. Fifty-six percent of utilities found online monitoring helpful when identifying influent WWTP slugs and preventing adverse WWTP or reuse system performance, as shown in Figure 3-36. Figure 3-37 shows the frequency of different online analyzers used for real-time monitoring, with pH, hydrogen sulfide (H_2S), conductivity, and temperature as the most frequent responses.

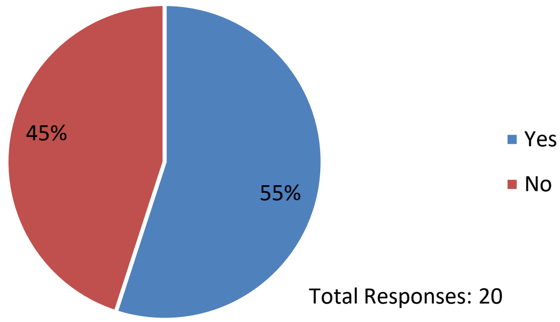

Figure 3-35. Percent of Utilities that Have Used Online Monitoring to Help Identify Industries Responsible for Adverse WWTP Quality and/or Illicit Discharges.

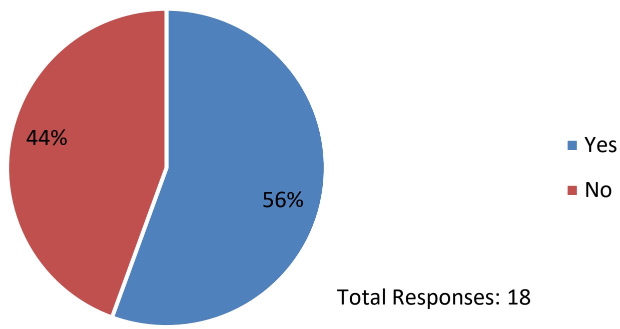

Figure 3-36. Percent of Utilities that Have Found Online Monitoring Helpful in Identifying Influent WWTP Slugs and Preventing Adverse WWTP or Reuse System Performance.

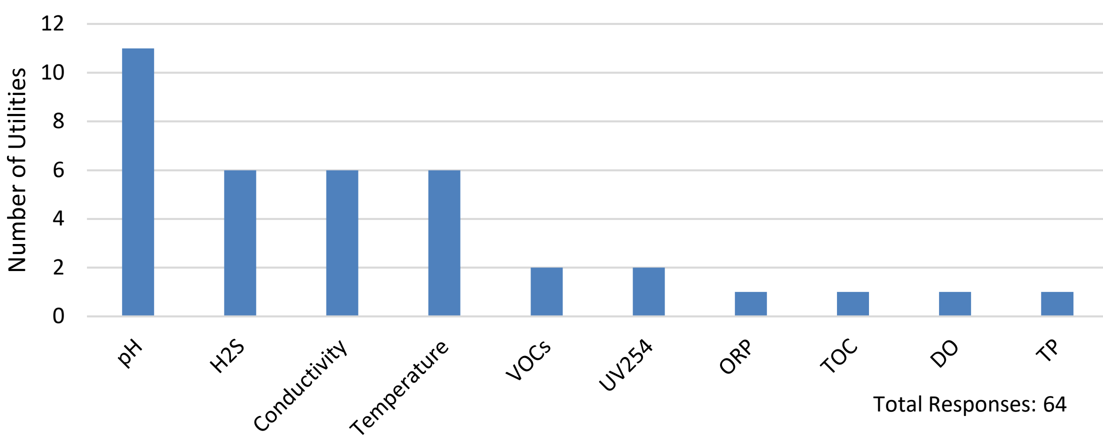

Figure 3-37. Parameters Included in Online Monitoring.

3.4 Summary

The survey responses provide a broad overview of how utilities operate industrial pretreatment programs and the types of industries and contaminants that pose the biggest challenges. Table

3-4 provides the objectives of the survey and how each objective was approached.

Table 3-4. Survey Objectives and Approach.

Objective	Survey Approach and References
1. Understand the prevalence of different types of industries that contribute to WWTP collection systems.	This chapter provides a good understanding of the types of industries that contribute to the surveyed utilities' collection systems as this question was directly asked in the survey. The prevalence of different industry types is shown in this chapter. The industrial categories identified as the most challenging were metals finishing, CWTs, food processing, and landfills. While this objective was achieved, additional research or investigation could be valuable to evaluate the most challenging industrial categories and identify recommendations specific to each category for the implementation of potable reuse systems.
2. Identify if there are specific contaminants, or groups of contaminants, that consistently pose problems to WWTP operation.	The survey results provide a wide array of contaminants that are challenging to WWTP operation. The results show that metals are the group that causes the most concern and has resulted in the majority of the site-specific or local limits that have been implemented to support One Water programs. This was the case for utilities with potable reuse systems and without potable reuse systems. While this objective was achieved, additional research could be performed on the potable reuse systems only to identify the contaminants that pose problems to the AWTP.
3. Understand the general framework of pretreatment programs for ESCPs.	A variety of questions presented in this chapter ask about different aspects of utilities pretreatment programs and ESCPs. Several examples were provided for how utilities reward and incentivize industries to comply with permit requirements. Some utilities identified that they have adjusted their pretreatment program or ESCP due to One Water initiatives, with the majority identifying additional sampling as the change. Various aspects of pretreatment programs and ESCPs were reviewed and summarized, including sampling, online monitoring, inspections, violations, enforcement, and how utilities have adjusted pretreatment programs to support One Water programs. The detail provided in this chapter achieves this objective.

The raw data from the survey is provided in Appendix B (utilities are anonymous). The reader is encouraged to review specific answers in this database if more detailed information is desired.

CHAPTER 4

Utility Case Studies

Several utilities were selected for case studies to learn more about their existing or forthcoming pretreatment programs and/or ESCPs. This section provides a summary of the case studies performed.

4.1 Introduction

Several potable reuse agencies have already developed robust ESCPs, an expansion of standard pretreatment programs. As discussed in previous sections, ESCPs are focused on potable reuse quality in addition to industrial discharge impacts to WWTP performance or NPDES compliance. Due to the lack of regulations or regulatory guidance, the breadth and depth of these ESCPs can vary widely. Further, many utilities are developing potable reuse programs and either have a relatively simple (and small) local limits program or no program whatsoever due to the size of their facility (<5 mgd). The goal of the case studies in this section is to understand the ESCP challenges facing several example utilities and to consolidate their best practices into a framework for ESCPs.

Broadly speaking, these case studies examine:

- WWTP Upsets and Compliance
- Challenges with advanced treatment processes or water quality targets
- Industrial Dischargers
- Sewer Use Ordinances
- Enforcement Response Plans
- Monitoring Programs; and
- Outreach Efforts

A select group of utilities were targeted for the case studies, including large and small, with and without pretreatment programs and ESCPs, and with different types of existing or future potable reuse projects, as shown in Table 4-1. Details from each of these seven case studies is provided below, followed by a summary table of key points.

Table 4-1. Utilities Included in Case Study Interviews.

Utility & Purification Treatment Train	Purification Treatment Train	Potable Reuse Project Status	Treatment Plant Size		Level of Implementation of Source Control
			Small (<5 mgd)	Large (>5 mgd)	
Morro Bay, CA	MBR, RO, UVAOP	Under Construction	X		Limited Pretreatment Program, now initiating new ESCP
Pismo Beach, CA	UF, RO, UVAOP	Predesign	X		Limited Pretreatment Program
Santa Cruz, CA	UF, RO, UVAOP	Under Construction		X	Detailed Pretreatment Program
Altamonte Springs, FL	Ozone, BAC, GAC, UF, UV	Demonstration-Scale		X	Detailed Pretreatment Program
LACSD, CA	(Three systems) Tertiary Spreading, UF/RO/UVAOP then groundwater recharge (two facilities), and MBR/RO/UVAOP	Systems 1, 2, and 3 are operational, System 4 is demonstration-scale		X[a]	Detailed Pretreatment Program
HRSD, VA	Floc/Sed, ozone, BAC, GAC, UV	Under Construction & Demonstration-Scale		X[a]	Detailed Pretreatment Program with Robust ESCP
City of Palo Alto	Future UF, RO, UVAOP	Planning		X	Detailed Pretreatment Program

[a] These utilities operate multiple WWTPs.
Notes: > = greater than; MBR = membrane bioreactor

4.2 City of Pismo Beach, California

Contact: Russell Fleming (rfleming@pismobeach.org) & Lauren Herrick (lherrick@pismobeach.org)

Source Control Program Status: The City of Pismo Beach maintains a limited pretreatment program focusing upon FOG at restaurants and hydrocarbon wastes associated with auto-repair and similar facilities.

Potable Reuse Project: Basis of Design is complete. Design, construction, and operation to be completed by 2026.

The City of Pismo Beach (population approximately 8,200), which operates a 1.9 mgd WWTP, is implementing an approximately 1 mgd potable reuse project, called Central Coast Blue. Pismo Beach and the neighboring partners are small towns with few IUs and do not currently have a formal, EPA-approved pretreatment program (which is only required for WWTPs greater than 5 mgd or those with significant non-domestic contributions that may impact the POTW). The City of Pismo Beach, based upon State of California regulations for potable reuse, will need to develop an ESCP prior to implementing their potable reuse project. That program will include an industrial waste survey (IWS), local limits, a sewer use ordinance, raw wastewater sampling, narrative limits, IU discharge sampling, source control outreach program, enforcement response plan, source mapping, a funding and resources report, and a collection system and treatment plant monitoring program manager.

These ESCP efforts will be extensive, as such, this interview with the City of Pismo Beach staff was an important first step in examining the industrial dischargers within their collection system and how those dischargers may impact a potable reuse program.

On November 3, 2020, the research team met virtually with Russell Fleming and Lauren Herrick from the City of Pismo Beach and the results of that interview are presented below as a summary, instead of the direct questions and answers. Following each subsection are potential actionable items that the City of Pismo Beach could implement to better understand source control challenges as they move to a future ESCP.

4.2.1 Plant Upsets

City of Pismo Beach staff indicates that plant upsets are infrequent and of marginal impact, happening in the late summer or early fall of each year. These "upsets" are minor and result in total suspended solids (TSS) increases and do not result in permit violations. The City of Pismo Beach's POTW is governed by an NPDES permit that allows for substantial ocean dilution, as such the permit numbers are not restrictive. Because the plant continuously provides a high-quality effluent (low ammonia, low TSS, low BOD), well below regulated levels, some periodic increases in TSS do not raise much concern.

The minor TSS upsets have not been correlated to an industrial discharge, but the nature of the issue suggests a discharge with a relatively abrupt rise in TSS (over 1 to 3 days) followed by several weeks to return TSS values back to background levels.

Potential Actionable Item: Establish baseline raw wastewater quality in the early summer and conduct detailed sampling of raw wastewater during a TSS upset event.

4.2.2 Industrial Dischargers

Approximately 95 percent of industrial discharges into the City's collection system is from restaurants; there are 76 restaurants in the town of less than 10,000 people. FOG are the primary discharge concerns for these IUs. Other dischargers include auto shops and power washers, where hydrocarbon discharge may be a concern. Nontraditional, but potentially important for potable reuse, are chemical discharges that may come from veterinary hospitals, urgent care clinics, dental offices, and medical complexes.

The conversation with City staff turned to waste haulers and septic stations associated with camping areas and a recreational vehicle (RV) park, as follows:

- **RV Sales and Service Center** – Earlier this year, City of Pismo Beach staff noticed a strong petroleum smell at a sewage lift station. City of Pismo Beach staff tracked the odor upstream to a manhole that only received waste from a particular RV center which provided service and sales to the region. The RV center's waste is not regulated or monitored and this current disposal practice suggests a chemical threat to the City of Pismo Beach's WWTP and potable reuse program.

- **Camping Areas** – Understanding the risk associated with unmonitored discharge systems, the City of Pismo Beach explained there are camping areas (which include RV camping) where waste is conveyed through the collection system to the City of Pismo Beach's WWTP. This waste does represent a potential threat to water quality due to the lack of control of discharge to such a system.
- **Waste Haulers** – Waste haulers contributing to the City of Pismo Beach's WWTP are only allowed to collect sewage from the region. Compliance with this geographical boundary is on the honor system, and thus a record or manifest of waste collection for haulers may be beneficial to better track wastewater source and quality.

Potential Actionable Items: Education and outreach programs can be used to better control effluent discharges from the RV and camping areas and head space volatile organic chemical (VOC) monitors can be installed in the headspace of sewer systems near these locations. Waste haulers can be better regulated through implementation of a manifest tracking system. Adequate control of waste hauler receiving stations and RV dump stations should be ensured throughout the region, including locked or controlled discharge locations, reporting or sign-in sheets, and hauled waste manifest systems.

4.2.3 Salts and Residential Water Softeners

According to City staff, there are no centralized desalting operations within the City of Pismo Beach, such as bottled water companies. Point of use water softening is used in the City of Pismo Beach, a decentralized approach to improve water quality. Based upon a small data set, TDS values are approximately 1,100 mg/L.

Potential Actionable Items: A review of electrical conductivity (EC) throughout the collection system, diurnally for several weeks or months, could provide information on salt loading into the collection system, and the existence, if any, of a larger scale desalting operation.

4.2.4 Monitoring and Enforcement

The City of Pismo Beach monitors and regulates industrial dischargers through its sewer use ordinance (SUO, Pismo Beach Municipal Code 13.14210-230 N.d.). Inspections are done annually. Sampling of industries is currently not done by the City of Pismo Beach. During the inspections, the City of Pismo Beach will review manifests for the auto mechanics. Noncompliance by industry is followed by a written notice of violation which may include a fine. With one exception, industry has worked to comply with City of Pismo Beach requirements. Generally speaking, the City of Pismo Beach is concerned if they have sufficient enforcement ability.

The City of Pismo Beach works closely with the Finance Department, based upon business licenses, to track new industries in their service area. Upon the generation of a new business license, City of Pismo Beach staff meets with the new industry and provides a welcome packet and BMPs and reviews expectations.

Potential Actionable Items: Increase the enforcement components of the SUO. Develop a collection system sampling plan to be implemented by the City of Pismo Beach to better monitor industrial discharges.

4.2.5 Outreach

Within the general community, some oil and grease issues have arisen within the neighborhoods and a door-knocking program has helped to reduce oil and grease disposal into the collection system. Nothing is currently done related to chemical discharges down the drain.

Potential Actionable Items: Develop educational materials on potable reuse and the need to keep both industrial and residential contaminants out of the sewer system. Develop an industry recognition program to encourage better water quality stewardship.

4.3 City of Morro Bay California

Contact: Joe Mueller (jmueller@morrobayca.gov)

Source Control Program Status: Currently implements a very limited pretreatment program. The ESCP is complete, but yet to be implemented.

Potable Reuse Project: Under construction, with a completion and operational date of 2022 for the treatment systems and 2023/2024 for groundwater injection.

The City of Morro Bay is implementing an approximately 1 mgd potable reuse project, called Our Water, which includes the construction of a new WWTP and advanced treatment facility. The City of Morro Bay is a small town (approximately 10,600 people) with few permitted IUs, and does not currently have a formal, EPA-approved pretreatment program (which is only required for WWTPs greater than 5 mgd or have other special circumstances that warrant one). The City of Morro Bay does currently implement a small pretreatment program, in accordance with the City of Morro Bay Municipal Code 1974 Title 13, including having a list of prohibited substances from discharge into the sewer, policies and procedures to enable the City of Morro Bay to address the potential need for pretreatment of conventional contaminants (BOD, TSS, oil and grease), and several restrictions on the discharge of septic tank wastes or treated septic tank wastes.

Because of State of California regulations for potable reuse, the City of Morro Bay has developed, but not yet implemented, an ESCP, which provides a different perspective than the small City of Pismo Beach, in which they have yet to develop an ESCP. Morro Bay's ESCP includes an IWS, local limits, a SUO, raw wastewater sampling, narrative limits, IU discharge sampling, source control outreach program, enforcement response plan, source mapping, a funding and resources report, and a collection system and treatment plant monitoring program manager. In total, the City of Morro Bay's ESCP effort provides important guidance for small utilities that have had to start from scratch to create the program.

On November 12, 2020, the research team met with Joe Mueller from the City of Morro Bay and the results of that interview are presented below.

4.3.1 Plant Upsets

In the initial survey, the City of Morro Bay listed "no WWTP impacts that could potentially be tied to collection system events." In our detailed interview, the team learned that the WWTP does see some effluent water quality variability, but they believe that to be seasonal. They have no recollection of a plant upset tied to an industrial discharger. Because of this track record, they do not currently have significant concerns about industrial dischargers with the exception of a bottled water company that removes salt (and currently discharges it to the sewer) and an industrial laundry facility that discharges an effluent to the sewer with a high pH.

It should be noted that historically there had been WWTP upsets which were directly tied to the disposal of RO cleaning solution from the City of Morro Bay's groundwater desalters. Those cleaning solutions are now neutralized and the impact to WWTP performance has gone away. The RO concentrate from the desalters is discharged directly to the ocean outfall.

4.3.2 Industrial Dischargers

The City of Morro Bay had to complete an IWS from scratch, reviewing every potential industry that may discharge to the collection system, resulting in hundreds of dischargers. The IWS is a lengthy process, even for a small community, based upon the following steps:

- Examined all the businesses in City of Morro Bay using their business license list, google search, and Envirofacts search.
- Categorized businesses based on information in the City of Morro Bay's records as well as supplemental information found online.
- Developed a questionnaire (digital) for businesses, followed by phone calls/emails to find out more about their discharge.
- Eliminated businesses whose discharges were determined to be primarily domestic.
- Short-listed businesses categorized into permit classes:
  - F for food service/processing
  - G for general permits
  - S for SIUs or potential SIUs
  - Non-responders
- The F-class businesses are those that the City will regulate primarily with regards to FOG, and do not represent a challenge to potable reuse.
- The G-class businesses are those that the City wanted to regulate, but they didn't fall under the definition of an SIU or CIU.
- The S-class businesses qualify as SIUs based on the definition.
  - Mission Linen: flow greater than 25,000 gpd
  - Culligan: high salinity/TDS
  - Aquarium: potential future brine discharge to sewer.

Through this process, the City of Morro Bay focused on two dischargers, the bottled water company and the industrial laundry. Both dischargers have signaled a willingness to cooperate with the City of Morro Bay. The aquarium will represent an important discharger in the future.

- Salt is clearly an important challenge, as high salt loads must be removed by the City of Morro Bay's future new RO system. The bottled water company currently discharges variable and sometimes high salt spikes into the sewer, which will challenge the production capacity of the future RO system (higher salt concentrations in the feed to the RO require higher driving pressure to attain the same recovery of water). Extended conversations have been had with the bottled water company to discuss potential methods to either equalize

the discharge to the sewer or remove the discharge entirely. The current plan is a collaboration with the bottled water company to equilibrate the discharge and change the discharge from the sewer directly into the City of Morro Bay's ocean outfall, termed a "Low Threat Discharge." The permit will belong to the City for this discharge, but the bottled water company will be required by the City of Morro Bay to meet flow and salt concentration values specified by the City.
- The aquarium, which is not a concern at this time because they are a future discharger, will be an SIU and will have narrative limits (e.g., no discharge of specific contaminants), with an option to impose site-specific limits and/or BMPs.
- The industrial laundry discharges more than 25,000 gallons per day, which is greater than 5 percent of the City of Morro Bay's wastewater flow. The laundry can provide both high and low pH wastewater, ranging from a pH of 6 to 10. In some cases, they overdose acid. As part of the ESCP, the laundry will need to install a dedicated and reliable pretreatment system, to which the laundry has indicated a willingness to follow the ESCP requirements. Those requirements, which have not yet been specifically detailed, will include pH, BOD, TSS, and oil and grease discharge limitations.

Other challenging dischargers are not anticipated by the City of Morro Bay, with several considerations:

- The City of Morro Bay's municipal code specifically does not allow any waste from outside the City. Further, the new WWTP and advanced treatment facility, which is under construction, is not designed to accept septage haulers.
- The City of Morro Bay has begun to talk to medical facilities, including hospitals, vets, medical centers, and dentists. Future conversations will focus on proper disposal of chemical contaminants.
- The City of Morro Bay currently has one RV dump station that is run by the City of Morro Bay, which will be eliminated in the coming months. However, there are two California State Park campgrounds that each have RV dump stations that feed directly into the sewer. Per agreement with the State, these dump stations are supposed to be tracked and logged, but this is currently not being done. Future efforts will engage with these dump stations and set up forms/documents to improve communication and compliance.
- The City of Morro Bay does have a mortuary. The City of Morro Bay will re-examine if there are any potential discharge water quality challenges that may be associated with this discharger.

The City of Morro Bay currently tracks industries that discharge to the sewer based on business licenses, using the "CityWorks" program. When a new business applies for a license to work within the City of Morro Bay, the automated CityWorks program will not approve that license until water utilities personnel evaluates the business for potential discharge/impact to the WWTP and provides a written approval.

4.3.3 Sewer Use Ordinance

The City of Morro Bay implemented a new SUO in late 2020 which gives the City of Morro Bay authority to permit and regulate industrial dischargers.

4.3.4 Enforcement Response Plan

As part of their ESCP, the City of Morro Bay developed an Enforcement Response Plan (ERP), which details how the City will address non-compliant dischargers. The City's expects the two large industrial dischargers (bottled water company and industrial laundry) to both be cooperative with the program but foresees greater compliance challenges with the more conventional food service businesses, who tend to push back politically.

4.3.5 Monitoring Program

The City of Morro Bay's current monitoring program, like most pretreatment programs, relies upon industry to self-monitor. The City of Morro Bay's current plan is that a future ESCP will include more detailed self-monitoring from dischargers coupled with verification checks by the City of Morro Bay (the amount to be determined but could be 25 percent). City of Morro Bay sampling would provide short notice (same day) ahead of sampling events.

The City of Morro Bay prepared a funding and resources report, which specifically details what City staff is needed to implement the ESCP, what sampling will be done, who will do it, and how frequently it will be done. In total, the effort is extensive, estimating approximately $150,000 in annual personnel costs, at least $60,000 in new monitoring equipment, and annual laboratory costs of greater than $5,000. This totals an increase in over $215,000 per year to implement the ESCP. The City of Morro Bay notes that today, before the ESCP and potable reuse program is implemented, staff is already the City of Morro Bay's highest expense. The development of a streamlined ESCP which may include online monitoring to enhance monitoring and enforcement, and reduce staffing needs, would be very beneficial to the City of Morro Bay.

4.3.6 Outreach

Outreach within a small community requires a small but dedicated program, which includes the various aspects of social media as well as flyers in the monthly billings. Prior engagement on rate setting was very successful using these methods. Further, the City of Morro Bay intends to build upon two other successful waste collection events that occur within the City of Morro Bay limits:

- County of San Luis Obispo has a successful Household Hazardous Waste program that is open every Saturday and located in Morro Bay. The program is well used by the residents of Morro Bay.
- The local fire and police department have a drug drop-off program one day per year. That program could be expanded in frequency and be part of a "no drugs down the drain" program.

4.4 City of Santa Cruz, California

Contact: Akin Babatola (ababatola@cityofsantacruz.com)

Source Control Program Status: Currently implements a detailed pretreatment program under the USEPA's NPP. The ESCP for Santa Cruz is yet to be established.

Potable Reuse Project: The potable reuse project is being led by the Soquel Creek Water District (SCWD). It is called Pure Water Soquel and is currently under construction with an operational date of late 2022. The first phase of the project will produce about 1 mgd of advanced treated water for groundwater recharge.

The City of Santa Cruz, in their support role to Pure Water Soquel, provides secondary effluent for subsequent purification using MF, RO, and UVAOP. Included in that role is City of Santa Cruz's existing—and potentially expanded—pretreatment program to meet the goals of the potable reuse program.

The City of Santa Cruz issues industrial discharge permits under the authority of its SUO under Chapter 16 of the City of Santa Cruz's administrative code. The City of Santa Cruz currently has three SIUs and one CIU.

On December 7, 2020, the research team met with Akin Babatola and Dave Martin from the City of Santa Cruz and the results of that interview are presented in the following subsections.

4.4.1 Sewer Use Ordinance

The City of Santa Cruz's existing pretreatment program, overseen by the Environmental Compliance department, is robust, providing protection of the WWTP, the ocean discharge, and the biosolids (allowing for reuse and disposal). The City of Santa Cruz's SUO, found in Chapter 16.08 of the City of Santa Cruz's administrative code (2021), provides the standards and the legal authority for enforcement of the pretreatment program. The SUO covers discharges to both the sanitary sewer and the storm drain system, among numerous other items.

The focus of the SUO is on the protection of the WWTP and NPDES compliance, and as such details may need to be adjusted to directly address concerns and actions necessary to protect potable reuse applications.

4.4.2 Plant Upsets

The City of Santa Cruz has only seen minor WWTP impacts from industrial dischargers to its collection system, notably alum wastes from the City of Santa Cruz's water treatment plant (WTP) which are discharged along with dewatered sludge. To the City of Santa Cruz's best knowledge, no recent industrial discharge event has impacted the WWTP or NPDES permit compliance. This performance is reflective of the robust pretreatment program in place coupled with the relatively low number of industrial dischargers.

4.4.3 Industrial Dischargers

The City of Santa Cruz's SUO utilizes an expanded set of local limits, referred to as "Specific Limitations on Wastewater Discharges." The parameters and respective concentration targets are shown in Table 4-2. Many of the parameters reflect the contaminants found in the Ocean Plan (California Environmental Protection Agency 1972), which sets receiving water limits for every California ocean outfall. Every discharger has different dilution credits based upon outfall and diffuser configurations and mixing characteristics. To address the latest version of the Ocean Plan, the City of Santa Cruz performed an extensive water quality survey of Ocean Plan parameters in 2010 for raw wastewater, secondary effluent, and in some cases probable dischargers, which led to the development of the concentrations listed below for all IUs.

The City of Santa Cruz also developed a broad stakeholder community, working with the public to explain the importance of setting contaminant targets for industrial dischargers. Of important note regarding public perception, the City of Santa Cruz needed to clearly explain that adding local limits for contaminants allows the City of Santa Cruz to limit the discharge of contaminants, as opposed to preventing the discharge of contaminants to the sewer system. Similar conversations may be needed in the future as it pertains to potable reuse.

Table 4-2. City of Santa Cruz Local Limits.

Contaminant	Concentration	Contaminant	Concentration
Arsenic	0.21 mg/L	MTBE	1.0 mg/L
Cadmium	1.57 mg/L	TTO[a]	1.0 mg/L
Chromium, total	35.65 mg/L	Phenols, total[b]	150 mg/L
Chromium, hexavalent	5.26 mg/L	Phenols, chlorinated[c]	0.60 mg/L
Copper	2.17 mg/L	Chlordane	1.48 x 10-5 mg/L
Cyanide	0.08 mg/L	DDT, o, p	0.011 mg/L
Lead	6.04 mg/L	Dieldrin	9.40 x 10-5 mg/L
Mercury	0.32 mg/L	endosulfan I	0.006 mg/L
Nickel	1.15 mg/L	Endrin	0.002 mg/L
Selenium	96.28 mg/L	heptachlor	0.00014 mg/L
Silver	0.71 mg/L	heptachlor epoxide	1.39 x 10-5 mg/L
Sulfide (dissolved)	0.20 mg/L – maximum monthly average	hexachlorobenzene	23.50 mg/L
	1.0 mg/L – maximum instantaneous	Naphthalene	2,350 mg/L
Suspended solids	3,000 mg/L	Phenanthrene/ Anthracene, C1	2,349.99 mg/L
Zinc	25.23 mg/L	Anthracene	2,422.68 mg/L
pH	5.0 - 10.0 (allowable range)	Fluoranthene	123.38 mg/L
Total petroleum hydrocarbons	100 mg/L	8 – PCB	0.000138859 mg/L
Temperature	≤104°F (40°C)	2,3,7,8-TCDD	2.53 x 10-9 mg/L
Oil or grease of animal or vegetable origin	300 mg/L (unless exempt by Section 16.08.190)		

[a] TTO is defined as the sum of all individual compounds listed in 40 CFR 433.11e with quantifiable concentrations greater than 0.01 mg/l when measured using test methods approved under 40 CFR 136 or other methods approved for NPDES monitoring, and other toxic organic compounds as determined by the director.
[b] Phenols, total, by EPA Method 420.1.
[c] Phenols, chlorinated, is defined as the sum of 2-chlorophenol, 2,4-dichlorophenol, pentachlorophenol, 2,4,6-trichlorophenol and 4-chloro-3-methylphenol (p-choloro-m-cresol).
Notes: °C = degree(s) Celsius; °F = degree(s) Fahrenheit; TTO = Total Toxic Organics

The City of Santa Cruz has also set limits for specific industries that do not apply to all industries, which provides a template for future industry-specific limits for potable reuse. In particular, the City of Santa Cruz set TOC and caffeine limits to dischargers to the storm drain system. These limits resulted in the development of BMPs for the subjected dischargers. Twice caffeine and TOC were detected, at levels above, and later, consistent with domestic sewage, within a storm drain during routine monthly monitoring of MS4 ocean outfalls. Contamination was subsequently source-tracked upstream to a specific industry. The first incident resulted from a sewer overflow, created by a failed outdoor sump-pump. The second incident resulted from poor housekeeping of their solid waste bin, which contaminated rain runoff. In both cases, the City of Santa Cruz prohibited any measure of each analyte in stormwater flows from the facility. During cleanup, the facility routed contaminated water to the sewer at a point just preceding discharge to the City of Santa Cruz's MS4 discharge location

Pertaining to industrial discharge permits, the City of Santa Cruz's Environmental Compliance department closely coordinates with the City of Santa Cruz's Planning Department on all new business licenses, allowing for close tracking of new industrial dischargers. The City of Santa Cruz currently has three SIUs, which present minimal challenges to the City of Santa Cruz:

- City of Santa Cruz's WTP, which is due to the discharge of the alum sludge.
- Santa Cruz Nutritionals, which is due to flow (greater than 25,000 gallons per day [gpd]) and some concerns related to pH.
- University of California at Santa Cruz, based upon flow being greater than 25,000 gpd.

The City of Santa Cruz has one CIU, Persys Engineering—a metal resurfacing company used for the information technology industry—which also presents minimal challenges to the City of Santa Cruz. The City of Santa Cruz also noted that a city-run landfill, which is not an SIU or CIU due to low flows and non-hazardous materials, adds landfill leachate at a constant rate to the sewer system and has not caused any related challenges to the WWTP.

Beyond the SIUs and CIU, the City of Santa Cruz has 450 permitted industries. Minor concerns from those industries include:

- Oil and grease from food service and vehicle service.
- Oil and grease and other waste products from auto shops. Auto shops are inspected annually, with additional inspections as needed, but are not typically sampled. The typical inspection is visual with review of Hazardous Waste Manifest System documents and verification of proper disposal of waste automobile solids and fluids. BMPs are provided to the auto shops.
- Organic loads from breweries: With the decrease in water use and the addition of brewery organic loads, there is concern about the impact on biological performance at the WWTP.

The City of Santa Cruz does regulate dental offices according to 40 CFR 441.50, requiring submission of the One-Time Compliance Report addressing the use of amalgam separators to eliminate discharge of amalgam that contains toxic metals (e.g., mercury). The County of Santa Cruz monitors discharges from two local hospitals.

The City of Santa Cruz will accept hauled waste at their WWTP, as follows:

- Septic (domestic wastewater from septic tank pumping in Santa Cruz County)
- Construction sites (that have treated groundwater)
- Food waste

The City of Santa Cruz does not currently allow for "Porta-potty" type wastes or wastes from centralized treatment facilities. However, there may be a potential centralized waste treatment facility in the future which should be closely considered and monitored as to how it could impact the WWTP, NPDES permit compliance, and future potable reuse.

The City of Santa Cruz does have a large RV community, with no permitted dump site within the City. It is not known how or where RV wastes are discharged but it is speculated to occur within State Park campgrounds, which have limited to no supervision or manifests (Hazardous or Domestic Waste Manifest System). Future potable reuse efforts should consider if or how to better handle or monitor RV waste disposal.

4.4.4 Interagency Agreements

A detailed agreement "by and between SCWD and the City of Santa Cruz Regarding Source Water, Design, Construction, Start-Up and Ownership of the Tertiary Facility Component of the Pure Water Soquel Program" was signed on July 19th, 2019. This section provides abridged excerpts from this agreement. Relevant to pretreatment/source control, the agreement stipulates:

- The City of Santa Cruz will continue to operate its comprehensive pretreatment program in accordance with the NPP.
- SCWD will pay for the capital cost of any additional industrial wastewater pretreatment required for advanced treatment or improvements needed to address wastewater source issues that could adversely affect the advanced treatment or Pure Water Soquel system's water quality or production.
- Costs of implementation of additional pretreatment program elements required for advanced treatment will be split by the SCWD and the City of Santa Cruz based upon volume of tertiary treated water flow used by each party.

In addition to the partnership with the SCWD for the Pure Water project, the City of Santa Cruz partners with the County of Santa Cruz (County) to accept and treat County wastewater on a contract basis. Wastewater from the County's collection system is discharged to the City's collection system and subsequently treated at the City of Santa Cruz's WWTP. The County currently contributes approximately 40-45 percent of conventional contaminants into the City's WWTP. The County maintains a similar local limits program to the City of Santa Cruz, as the City of Santa Cruz must receive, treat, and discharge wastewater from the County. The County has five SIUs with potential to affect WWTP operations, each discharging less than 25,000 gallons per day.

4.4.5 Enforcement Response Plan

The City of Santa Cruz has a detailed ERP (City of Santa Cruz 2008) following the requirements set by the Section 403.8(f)(5) of the CFR. The ERP outlines the procedures followed by pretreatment program staff and management to identify, document, and respond to pretreatment violations. The ERP also describes the duties of the Enforcement Compliance Inspector, including methods used to determine compliance with applicable regulations and procedures to review compliance data. Within the ERP are:

- Detailed tiered compliance definitions, including "consistent compliance," "inconsistent compliance," and "significant noncompliance", which contain the allowable variations from

prescribed limits and appropriate remedies.
- Detailed enforcement actions for Informal Enforcement (voluntary compliance) and Formal Enforcement (administrative and judicial remedies).
- An Enforcement Response Guide (ERG), which lists routine response actions including Verbal Warnings, Warning Notices, Notices of Violation, Administrative Citations, and Compliance Meetings. The ERG includes a guide that describes violations and indicates minimum enforcement actions.

The ERP describes enforcement actions if Compliance Meetings fail to address the problems, including: Cease and Desist Order and Withdrawal or Modification of the Industrial User's Permit.

The focus of the ERP is on the protection of the WWTP and NPDES (ocean discharge and biosolids) compliance. As such, details may need to be adjusted to directly address concerns and actions necessary to protect potable reuse applications.

4.4.6 Monitoring Program

The City of Santa Cruz's monitoring program includes both inspection and sampling by the City of Santa Cruz and self-sampling by the industry, as follows:

- Industries are inspected annually, at a minimum.
- Sampling of SIUs is conducted annually by the City of Santa Cruz, but quarterly by the industry.
- The CIU is sampled annually by the City of Santa Cruz and twice annually by the CIU (as it is a batch discharger). Five 100-gallon batches from the CIU pretreatment system are discharged to the sewer each week on average.
- The self-monitoring by the SIUs and CIU is based upon a reduced list of contaminants, whereas the annual sampling by the City includes the full local limits list summarized previously. The self-monitoring requirements of each SIU are evaluated based on any potential to discharge each contaminant. For example, the City's SIU that performs foods manufacturing is not required to monitor metals, PCBs, TCDDs, volatiles, semi-volatiles, or pesticides regularly. However, the City of Santa Cruz annual monitoring, as well as quarterly during local limits reevaluations, monitors for these contaminants.

The City of Santa Cruz has developed an inventory of anticipated contaminants from each industry. For example, the one CIU within the City of Santa Cruz utilizes, and thus disposes of, nitric acid, hydrochloric acid, sulfuric acid, alcohol, acetone, hydrogen peroxide, sodium hydroxide, and potassium hydroxide. Keeping and updating these chemical inventories is important for a future potable reuse project. Low molecular weight compounds, such as acetone, present a pass-through risk to the advanced treated water, as acetone is not well degraded biologically, not well-removed by membranes, and not well-removed by advanced oxidation. Each chemical on these inventories should be cross checked with treatment performance as well as discharge concentrations and dilutions with other wastewaters to determine whether they pose a challenge for potable reuse water quality.

The City of Santa Cruz has had success tracking abnormal water quality of unknown origin back to the source. In one notable event, high VOC levels were traced through the collection system to one SIU as follows:

- On December 10th, 2020, the City of Santa Cruz's Operations department approached the City of Santa Cruz's Environmental Compliance department regarding two unusual coincident observations in wastewater--not yet affecting normal plant operations. Operations reported that all WWTP staff noticed a sulfide smell. Operations' subsequent visual inspection of incoming wastewater observed a more yellow tint of influent than normal.
- Environmental Compliance began investigation of City and County influent samples, checking each trunkline for VOCs and checking with the County for unusual occurrences or maintenance activity.
- One trunkline from the City of Santa Cruz yielded an 18 ppm reading on a VOC meter, 10 times higher than other trunklines.
- Environmental Compliance checked the pretreatment systems of SIUs serviced on this sewer line and found yellow wastewater with a pineapple perfume yielding a 25 ppm reading on the VOC meter discharging from a food manufacturing facility— likely the source of the more yellow WWTP influent and VOC readings.
- Concurrently, the County communicated their Wastewater Collections Division has been coincidently pigging sewer mains—a known activity that produces sulfide smell at the WWTP and the likely cause of the reported smell at the WWTP.

No interference or pass-through occurred at the WWTP during 2020 and no monitored contaminants at the WWTP were affected as the result of these reported observations in influent.

Looking to a future Pure Water Soquel project, the City of Santa Cruz has begun to monitor for additional drinking water related contaminants, evaluating raw sewage from the City of Santa Cruz, raw sewage from the County, effluent from the City of Santa Cruz's WWTP, and SIU discharges. The contaminant list and frequency of monitoring is still undergoing review and evaluation, but is anticipated to include: Acetone, n-Butylbenzene, sec-Butylbenzene, tert-Butylbenzene, Carbon disulfide, 2-Chlorotoluene, 4-Chlorotoluene, Diazinon, Dichlorodifluoromethane (Freon 12), 1,4-dioxane, Ethylene glycol, Formaldehyde, Gross Alpha, Gross Beta, Methyl isobutyl keton (MIBK), N-Nitrosomorpholine (NMOR), Perchlorate, n-Propylbenzene, Tertiary butyl alcohol, 1,2,3-Trichloropropane, 1,2,4-Trimethylbenzene, Tritium, and 1,3,5-Trimethylbenzene.

4.4.7 Outreach

The City of Santa Cruz has an industrial outreach campaign, which includes:

- BMPs for restaurants, vehicle service (auto shops), and construction sites
- Annual meetings in person with each industry
- Use of media, including TV, Facebook, and movie theaters for information sharing

The City of Santa Cruz recognizes the contributions from industries annually at a Pollution Prevention Event. At the annual event, new programs are announced and described. The City of

Santa Cruz also publishes non-compliances in the local newspaper.

4.4.8 ESCP Cost and Resources

As the City of Santa Cruz already has a robust pretreatment program, the ESCP is not expected to be a significant cost or resource increase. The current pretreatment program has three full-time employees and an annual budget of $880,000 per year. This team will be able to fulfill the majority of the anticipated ESCP tasks as they are largely similar to the current NPP tasks. However, the increased analytical burden will require additional cost and resources. The City of Santa Cruz estimates it will cost around $75,000 per year in analytical costs for the drinking water focused and emerging contaminants and that they will need to budget approximately $25,000 per year for trained personnel to support the sampling. The total incremental cost of the ESCP is estimated to be $100,000 per year, which is 11 percent of the current pretreatment team budget.

4.5 City of Altamonte Springs, Florida

Contact: David Ammerman, P.E. (dammerman@altamonte.org), Division Director Water, Wastewater, Reuse

Source Control Program Status: Currently implements an industrial pretreatment program. Developed an ESCP in June 2020.

Potable Reuse Project: The City of Altamonte Springs completed a 1-year demonstration from September 2016 to September 2017 for a pilot-scale carbon-based potable reuse treatment train called "pureALTA." The pilot employs ozonation, biofiltration, ultrafiltration, GAC adsorption, and UV disinfection to treat tertiary-filtered wastewater effluent. Since then, the pilot has been in operation to serve as a platform for research and offer public tours for outreach and education. The City of Altamonte Springs anticipates moving toward a 300,000-500,000 gallons per day facility in the future (timeline undetermined at the time of writing this report) to augment their potable water supplies.

The City of Altamonte Springs issues industrial discharge permits under the authority of SUO under Chapter 26 of the City Ordinances. The City of Altamonte Springs currently has one SIU that is also a CIU.

On December 18,2020, the research team met with David Ammerman from the City of Altamonte Springs and the results of that interview are presented below.

4.5.1 pureALTA Demonstration

The pureALTA project, which is a demonstration-scale potable reuse project, receives tertiary-filtered effluent from Altamonte Springs Regional Water Reclamation Facility (ASRWRF) for subsequent purification. The project included intensive water quality sampling of regulated and unregulated contaminants for nearly a year. Sampling was conducted in the feed to the purification system, in the effluent of the purification system, and at points in between. The results consistently demonstrated high-quality filtered secondary effluent that was readily treated to meet and exceed potable water goals. The results from this study add confidence that the current industrial pretreatment program for the City of Altamonte Springs, with a few minor modifications, is sufficient to meet the goals of a future potable reuse program. Specific action items to be considered ahead of a future potable reuse project include:

- Examine metals concentrations in the feed to the purification system and after purification (e.g., aluminum); and
- Identify all regulated contaminants and select unregulated contaminants with known health risks based upon their concentration in the tertiary effluent and the reliability of treatment by the purification process. For contaminants that present a potential pass-through risk, identify which industries these contaminants emanate from and identify ways to reduce the discharge of such contaminants.

4.5.2 Plant Upsets

The City of Altamonte Springs has not seen any significant impacts to their ASRWRF due to industrial discharges. This performance is reflective of the relatively low number of industrial dischargers within the City of Altamonte Springs.

4.5.3 Industrial Dischargers

The City of Altamonte Springs, like any utility with a regulated pretreatment program, requires SIUs and CIUs to receive a permit from the City of Altamonte Springs and meet specific local limits for their discharged water quality. The City of Altamonte Springs does not require discharge permits for other industries that are not SIUs or CIUs.

In conversation with the City of Altamonte Springs, there does not appear to be industrial dischargers, large or small, that present a challenge to water quality. The City of Altamonte Springs has one SIU, which is a metal finishing facility and thus also a CIU, and has no challenges with this facility. The City of Altamonte Springs has had potential concerns raised and later addressed related to industrial dischargers that are not CIUs or SIUs, as shown in these examples:

- Small Chemical Discharger: a manufacturer of electronic cigarettes that produces nicotine solutions, as well as the carrier fluids that accompany the nicotine, notified the City of Altamonte Springs that they would be discharging a hazardous waste (nicotine) as part of normal operations. The City of Altamonte Springs contacted the Florida Department of Environmental Protection, who inspected the site and concluded that no action was needed.
- Small Bottled Water Discharger: the City of Altamonte Springs was recently approached by a water bottling company to receive a business license. After review of the production volumes and waste products, the license was approved, and the company was allowed to discharge.

The City of Altamonte Springs does have a large number of medical facilities in town. The City of Altamonte Springs currently receives medical wastes from these facilities and has not communicated specifically to them regarding pureALTA. The City of Altamonte Springs does, however, intend to initiate a broader outreach campaign to all dischargers in advance of pureALTA going full-scale.

Looking to the future, the City of Altamonte Springs recognizes the need to have a more formal and documented process to identify and vet existing and new businesses in town prior to the approval of businesses licenses and start of operation. Such a program is now under development and may include the following steps:

- Implementation of a protocol which requires that any new application for a water/wastewater related business permit require communication between the Planning Department and the Water/Wastewater/Reuse Department.
- Review of all proposed contaminants to be discharged, the volume of contaminants to be discharged, and any pretreatment that may be employed.
- Approval of said discharge by the Water/Wastewater/Reuse Division within the City of Altamonte Springs.

4.5.4 Sewer Use Ordinance

The City of Altamonte Springs's SUO gives the City legal authority to enforce local limits under Chapter 26 of the City Code. Penalties for violation of permitted limits include a preliminary or permanent injunction and potentially fines.

The City of Altamonte Springs's SUO provides a lengthy list of prohibited discharges, including general and specific parameters which, when combined, provides the City of Altamonte Springs flexibility in enforcement of limits on industry, including: waste slugs, flammable materials, toxic chemicals, solid or viscous substances, compounds that impact the WWTP, low or high pH, cyanide, high temperature, FOG, strong acids and concentrated plating solutions, iron, chromium, copper, zinc, phenols, radioactive wastes, and any compound that impacts the reclamation of water.

Waste haulers are not allowed per the SUO, unless specifically approved for discharge at specific locations.

The City of Altamonte Springs's local limits, last updated in 2008, includes arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, silver, and zinc.

The SUO contains "remedies for prohibited discharge," which is essentially an ERP, which includes:

- Suspend service and/or suspend the industry's discharge permit.
- Require pretreatment to meet standards.
- Require control over the quantities and rates of discharge.
- Require payment to cover the City of Altamonte Springs's costs.
- Other remedies in the event of continued noncompliance.

The single SIU within the City of Altamonte Springs has a detailed permit which includes requirements for pretreatment (pH adjustment, bag filters, activated carbon, ion exchange) and a detailed sampling list for compliance, provided here as an example:

- Categorical Limits: cadmium, chromium, copper, lead, nickel, silver, zinc, cyanide, total toxic organics

- Local Limits: copper, lead, nickel, pH, TSS, BOD, chemical oxygen demand (COD), total nitrogen, oil and grease, total phosphorus

4.5.5 Source Tracking

Should the City of Altamonte Springs see water quality impacts at the ASRWRF, NPDES discharge concerns related to water quality, or AWT quality concerns, the planned approach to source tracking is as follows:

- Identify if the water quality concern is also associated with a change in a surrogate parameter (e.g., EC, pH).
- Screen water quality parameters (e.g., surrogates or specific parameters) within the sub-sewer sheds, which culminate at the various lift stations within the collection system.
- Once the water quality challenge is isolated within one sub-sewer shed, collect subsequent samples at nodes within the sub-sewer shed as well as at suspect industries.

4.5.6 Monitoring Program

The City of Altamonte Springs's monitoring program includes both inspection and sampling by the City of Altamonte Springs and sampling by the industry, as follows:

- Industries are inspected annually.
- Sampling of SIUs is conducted annually by the City of Altamonte Springs, but twice annually by the industry.

The SUO also provides clear requirements as to the reporting and record keeping required of SIUs, including quarterly reporting unless otherwise specified.

The City of Altamonte Springs has also implemented online monitoring of recycled water quality using online pH and online EC monitoring in addition to the traditional monitoring of turbidity, chlorine residual, and flow out of their water reclamation plant. That data already tells some interesting stories which need further evaluation, including:

- Diurnal pH patterns
- Diurnal EC patterns
- Rising EC values, though gradual
- Clear evidence that pH and EC vary opposite of each other (e.g., low pH and high EC, high pH and low EC) as shown in Figure 4-1.

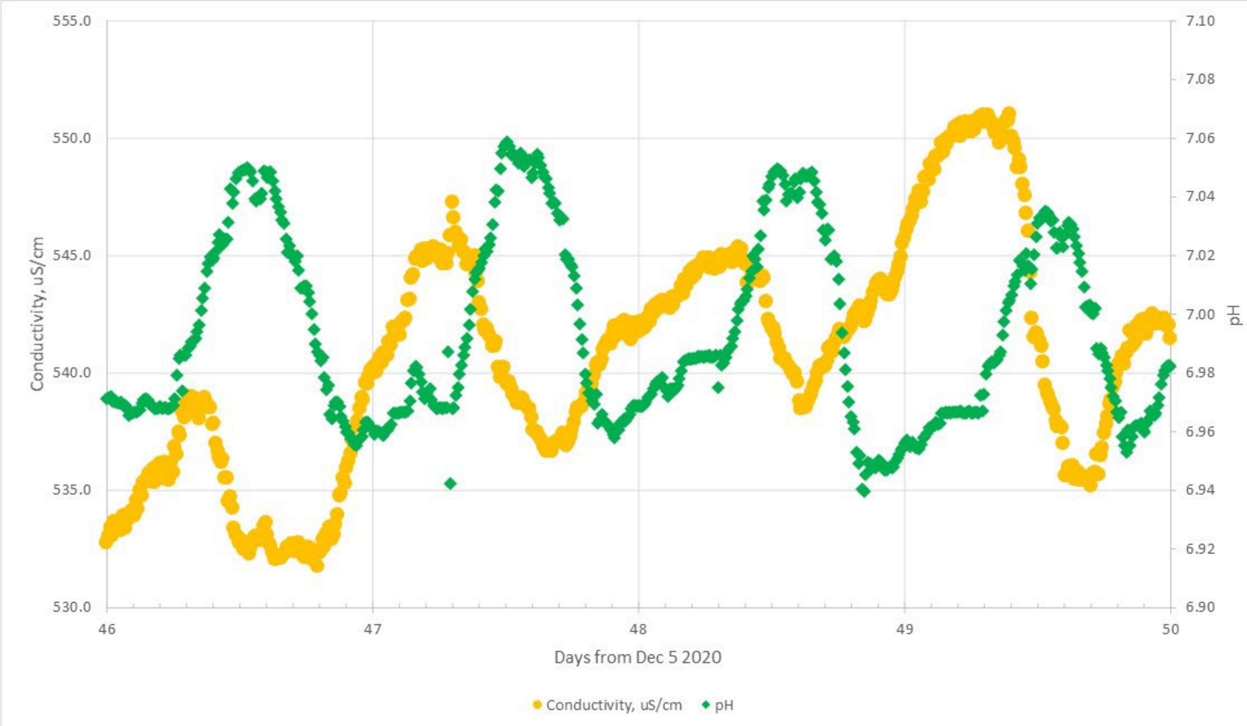

Figure 4-1. Diurnal pH and EC Patterns.

Looking to the future of potable reuse, a broader online monitoring program, supplemented by bench-scale studies, within the pureALTA process will be implemented. These sensors and tests, many of which are already in operation on the pureALTA demonstration, will track water quality and treatment system performance, and divert flow away from pureALTA based upon abnormal process readings, the values of which will be determined during full-scale design.

4.5.7 Outreach

The City currently does not have an outreach campaign to new industry. Violations of local limits are public record and are published in the local newspaper per the SUO.

4.5.8 Enhanced Source Control Program Additions to Pretreatment Program

In total, the City of Altamonte Springs will be adding substantial work efforts for the future ESCP. In 2020, the City completed the first step evaluation of these efforts, which include:

- Enhanced collection system and treatment systems monitoring program
  - Increased monitoring at nodes in the collection system for industry-specific monitoring as well as local limits. The frequency of increased monitoring is to be determined.
  - Using a specific contaminant inventory, monitor both the feed (secondary or filtered effluent) and finished water from the pureALTA system. The proposed contaminant list is bulleted below, with the frequency shown in Table 4-3.
    - Primary Florida MCLs for inorganic compounds, radionuclides, disinfection byproducts, organic compounds (per 62-550.310 Florida Administrative Code [F.A.C.]). 2021. Reuse of Reclaimed Water and Land Application. 62-610. August 8. F.A.C.).

        - Secondary MCLs (per 62-550.320 F.A.C.).
        - Regulated contaminants for IPR (per 62-610 F.A.C.).
        - Unregulated contaminants that serve as indicators for advanced treatment (Table 4-4).
        - Unregulated contaminants that have public health implications, listed in Table 4-5.
    - A tailored sampling program that includes the long inventory list of contaminants (summarized above) which can be much reduced to a short list of contaminants based upon the magnitude of detections relative to health-based goals and treatment system performance.
    - Focusing on the individual advanced treatment systems, a rigorous online and grab sampling plan for analysis of key process or water quality parameters. This includes TOC (online and grab), nitrate and nitrite (online and grab), turbidity (online and grab), UVT (online and grab), and BOD (grab).
- Rigorous source tracking: the City of Altamonte Springs identified a broad range of non-SIU/CIU dischargers and organized them based upon mass loading of contaminants per month to the collection system. The City of Altamonte Springs also identified dischargers of medical wastes and sewer connections from neighboring cities that contract the City of Altamonte Springs to treat their waste. A graphic of that work is shown in Figure 4-2, highlighting the collection system, lift stations, and the discharger locations. Figure 4-3, also included below, breaks down the sewer sheds that can be sampled to track down challenging water quality discharges.
- Increased industrial and public outreach and engagement, potentially including:
    - Industry
        - Review of all business licenses annually for relevance to water quality
        - Webinars and/or in-person periodic meetings with CIUs, SIUs, and all industrial dischargers
        - Development of industry-specific standard operating procedures (SOPs)
        - Periodic audits and meetings with specific dischargers
    - Public
        - Education of the water reuse program and water cycle
        - Household drug and chemical disposal programs/recommendations
        - Bilingual outreach
        - Outreach electronic and by mail (in billings)

Table 4-3. City of Altamonte Springs Monitoring Plan for Class of Contaminants, Location, and Frequency.

Class of Contaminants	Monitoring Plan[a]		
	Collection System	ASRWRF Secondary Filtered Effluent	pureALTA Finished Water
Industrial Discharge	Monthly (by permit requirement)	Monthly	Monthly
Local Limits	Monthly	Monthly (Year 1), Quarterly starting Year 2	Monthly
Regulated Contaminants (MCLs, SMCLs)[b]	--	Monthly (Year 1), Quarterly starting Year 2	Monthly
Unregulated Contaminants[c]	--	Monthly (Year 1), Quarterly starting Year 2	Monthly

[a] Monitoring frequency for industrial discharger (SMF) will be determined by flow, as outlined in industrial permit.

[b] Per 62-550.310 (MCLs), 62-550.320 (Secondary MCLs), and 62-610 F.A.C. (contaminants specific to potable reuse in Florida).

[c] Refer to Tables 4-5 and 4-6 for unregulated contaminants.

Table 4-4. Altamonte Springs Recommended Unregulated Contaminants to be Analyzed that Serve as Indicator Trace Organic Chemicals in a Potable Reuse Program.

Contaminant	Use of Target Contaminant	Maximum Recommended Value[a] (ng/L)
Atenolol	Pharmaceutical, beta blocker	70,000
Atrazine	Herbicide	1,000
Bisphenol A	Plastics additive	200,000
Carbamazepine	Pharmaceutical, anti-convulsant	1,000
Diclofenac	Pharmaceutical, nonsteroidal anti-inflammatory drug	1,800
Gemfibrozil	Pharmaceutical, lipid regulating agent	45,000
Ibuprofen	Pharmaceutical, pain reliever	400,000
Meprobamate	Pharmaceutical, anti-anxiety medication	260,000
Musk Ketone	Fragrance additive	350,000
Naproxen	Pharmaceutical, pain reliever	220,000
N,N-diethyl-meta-toluamide (DEET)	Insect repellant	2,500,000
Phenytoin	Pharmaceutical, anti-convulsant	6,800
Primidone	Pharmaceutical, anti-convulsant	10,000
Sulfamethoxazole	Pharmaceutical, antibiotic	35,000
Triclosan	Biocide	350
Trimethoprim	Pharmaceutical, antibiotic	70,000
TCEP	Fire retardant	1,000

[a] Source: Crook et al. 2016.

Table 4-5. Altamonte Springs Recommended Unregulated Contaminants of Interest from a Public Health Standpoint to be Analyzed for a Potable Reuse Program.

Contaminant	Criterion	Rationale	Source
PFOA	0.07 μg/L[a]	Known to occur, frequency unknown. On CCL4.[b]	USEPA Health Advisory.
PFOS	0.07 μg/L[a]	Known to occur, frequency unknown. On CCL4.	USEPA Health Advisory.
Perchlorate	15 μg/L 6 μg/L	Of interest, same analysis as chlorate and bromate.	USEPA Health Advisory.
Ethinyl Estradiol	None, close to detection limit if established.	Steroid hormone, should evaluate presence in source water. On CCL4.	(Framework for Direct Potable Reuse, Tchobanoglous et al. 2015)
17-ß-estradiol	None, close to detection limit if established.	Steroid hormone, should evaluate presence in source water. On CCL4.	(Bull et al., 2011)
Estrone	320 ng/L	Surrogate for steroids. On CCL4.	Based on an increased risk of stroke in women taking the lowest dose of conjugated estrogens.
NDMA	10 ng/L	Byproduct of ozonation and chloramination.	California Division of Drinking Water NL

[a] Per EPA fact sheet on HAL, when PFOA and PFOS are both found in drinking water, the combined concentrations of PFOA and PFOS should be compared with the 70 parts per trillion health advisory level.

[b] Contaminant Candidate List 4 (CCL4) - List of contaminants provided by USEPA that are currently not subject to any proposed primary drinking water regulations, but are known or anticipated to occur in public water systems.

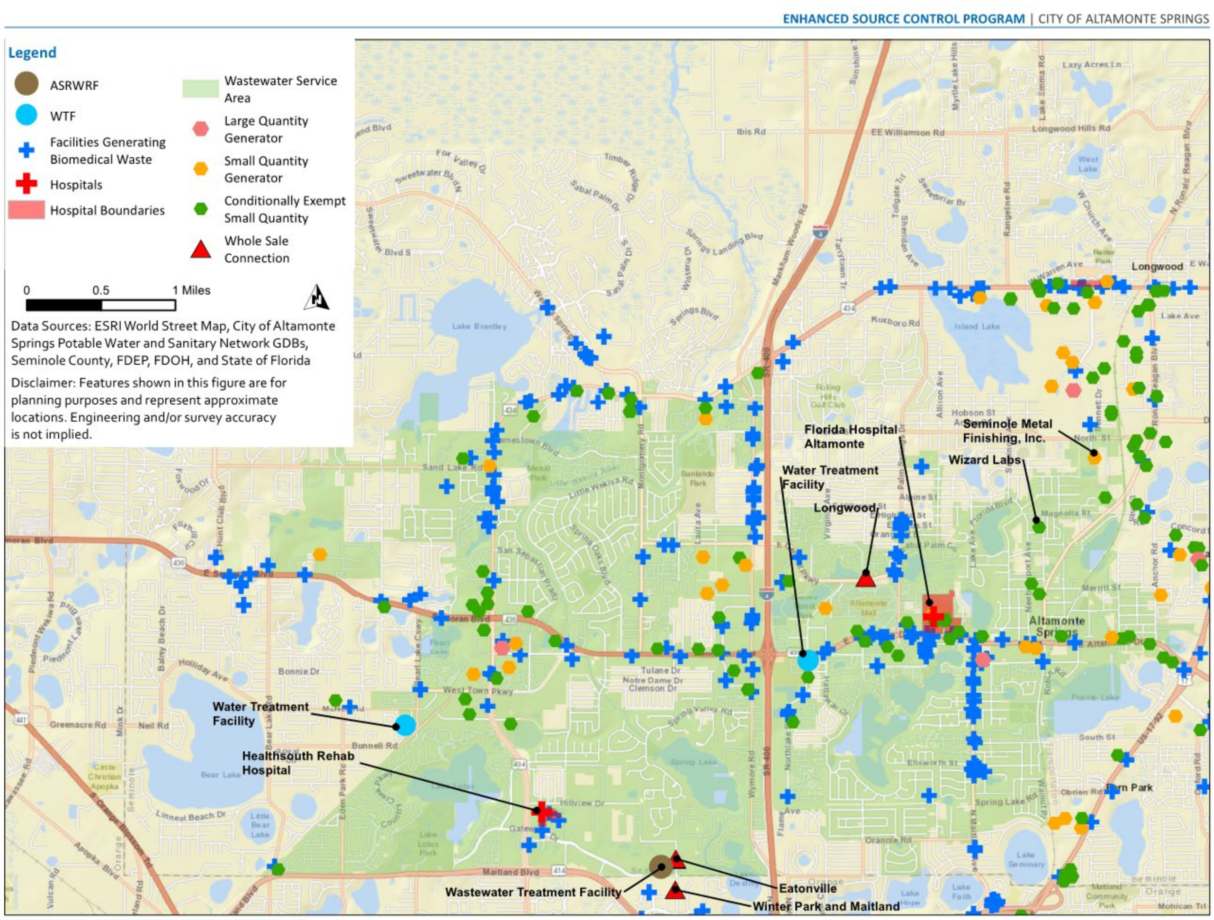

Figure 4-2. Mapping of Industrial Dischargers.

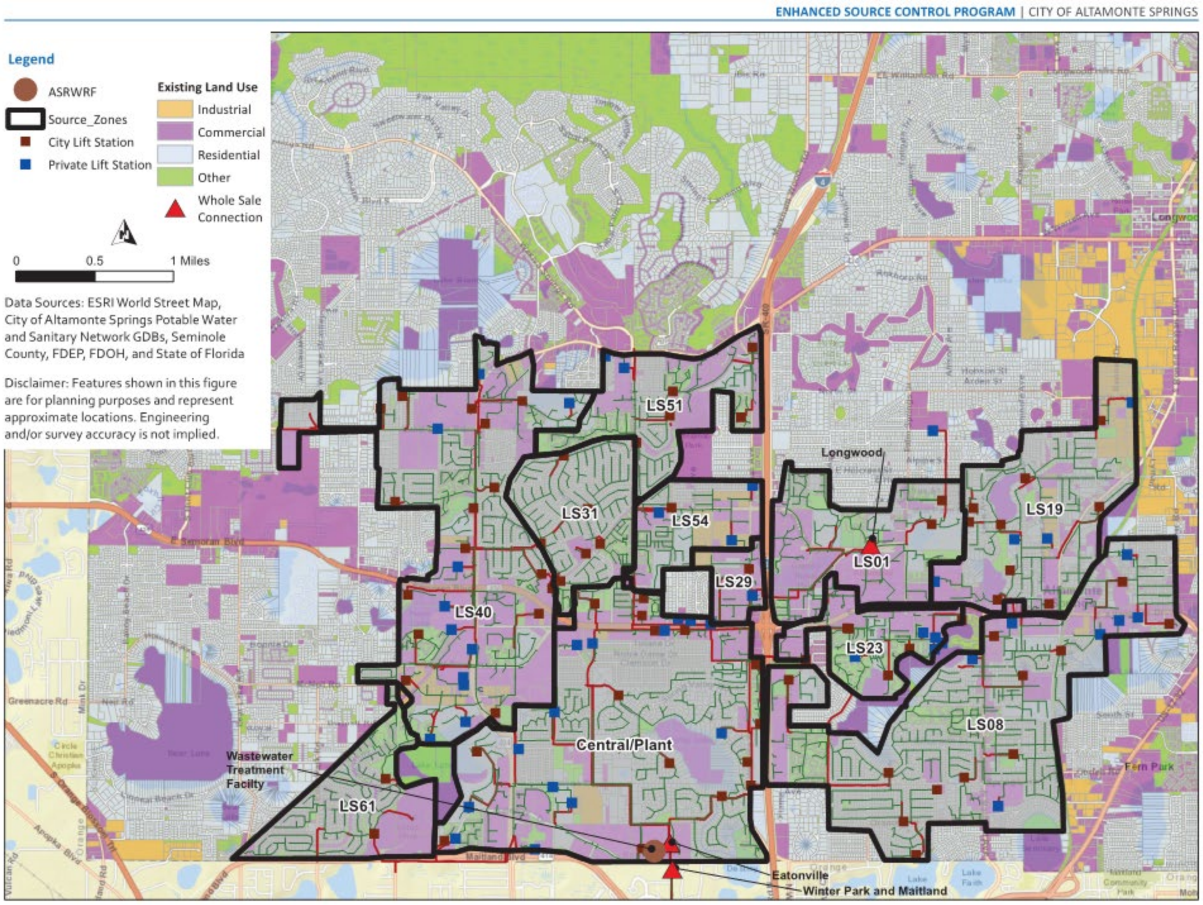

Figure 4-3. Mapping of Sewer Sheds.

4.6 Los Angeles County Sanitation Districts, California

Contact: Linda Shadler (lshadler@lacsd.org)

Source Control Program Status: Currently implements an extensive and detailed pretreatment program, meeting the objectives of the ESCP.

Potable Reuse Projects: The LACSD support a broad range of water reuse projects, including potable reuse projects (e.g., the Montebello Forebay Groundwater Recharge Project, the Metropolitan Water District of Southern California Advanced Purification Center Demonstration Project).

The Sanitation Districts' wastewater pretreatment program is broad, intended to protect all of the Sanitation Districts' water reclamation plants and the downstream permit compliance for both NPDES discharge and for potable reuse. The program includes:

- Collection of wastes from 850 square miles and 78 cities and unincorporated territory within Los Angeles County.
- Serving 5.7 million people in Los Angeles County.
- Tracking of all wastes to 11 water reclamation plants: Joint Water Pollution Control Plant, La Canada, Lancaster, Long Beach, Los Coyotes, Palmdale, Pomona, San Jose Creek (East and

West), Saugus, Valencia, and Whittier Narrows.
- Approximately 400 CIUs.
- Approximately 1,000 SIUs.
- Approximately 1,500 other industrial dischargers.

Spanning a period of months in 2020 and 2021, research team staff has met with Linda Shadler, Nikos Melitas, and Martha Tremblay and the results of those interviews are presented below. The extensive breadth of the Sanitation Districts program cannot be covered by a short summary, so the effort here focuses primarily on lessons learned and challenges overcome by Sanitation Districts staff, as well as a look ahead as the Sanitation Districts staff looks to support potable reuse from the Joint Water Pollution Control Plant (JWPCP).

4.6.1 Plant Upsets

Historically, the Sanitation Districts have seen upsets at several of their plants, including Pomona and Whittier. The aggressive pretreatment program now in place has minimized plant upsets. The Sanitation Districts have also dealt with water quality concerns (not necessarily violations or plant upsets) resulting from industrial discharge, including color issues at Los Coyotes, foam at Pomona (due to a carwash that poured soap into the sewer) and recent pH issues at Pomona (related to industrial cleaning events in the middle of the night which coincide with low flow, occurred in 2019 and 2020).

A review of one of the Pomona incidents is provided below, detailing the challenges and the Sanitation Districts' response. Of important note, all events, such as that chronicled below, are accessible in detailed Incident Reports. The event below occurred on October 16, 2019, and was mitigated within 24 hours.

- 5:05 a.m. – high influent pH witnessed at the Pomona Water Reclamation Plant (WRP) (value above 9). Shortly thereafter, an operator is dispatched to the Pomona WRP (which is unattended at night) to collect pH confirmation samples.
- 5:21 a.m. – plant staff contacts a supervising industrial waste (IW) inspector.
- 6:23 a.m. – a second high pH value is seen at the Pomona WRP, resulting in more confirmation sampling. The pH events were both brief, 15 minutes. The second confirmation sampling showed a pH of 9.36 for water that had a red/orange color. No color was seen in the earlier 5:05 a.m. pH spike.
- 8:05 a.m. – a third pH spike with no color is seen. Plant staff confirm that the pH spike was not due to any activities by the Sanitation Districts (such as caustic dosing) within the collection system. Two IW inspectors were assigned to investigate the problem and determine which discharger was creating the pH and color problem.
- Over the next 24 hours, IW staff investigated and sampled ten tributary industries that have the potential for both high pH and color. The culprit industry was found, faulty pH monitoring by the industry was noted, excessive dosing of sodium hydroxide was noted, a notice of violation was made to the industry, and the problem was abated.

Repeating several key aspects of the example above:

- The problem occurred at a remotely monitored plant, but within minutes staff was mobilized to perform confirmation sampling and troubleshooting.

- Within several hours, the problem was clearly determined to be sporadic high pH discharges to the collection system, one of which had high color.
- Due to thorough knowledge of the industrial dischargers within the subject collection system, a short list of dischargers which could create both pH and color challenges was identified.
- Deployment of IW staff to inspect and sample from the short list of dischargers resulted in the determination of the violating discharger and the cause of the violations, a citation was provided, and the problem was abated, all within approximately 24 hours of the initial high pH alarm.

4.6.2 Sewer Use Ordinance

The Sanitation Districts' Wastewater Ordinance provides the Sanitation Districts with the authority to implement and enforce their pretreatment program, as detailed in the sections below. The Wastewater Ordinance was first completed in 1972 and was amended in 1998.

4.6.3 Industrial Dischargers

Section 401 of the Sanitation Districts' Wastewater Ordinance requires each company discharging industrial wastewater directly or indirectly to the Sanitation Districts' wastewater collection and treatment system to apply for an industrial wastewater discharge permit for each sewer outlet. As part of the submittal process, dischargers must submit detailed information of their wastewater generating operations, install necessary pretreatment facilities, and periodically report flow and water quality for industries designated as SIUs. Through this program, the Sanitation Districts approves hundreds of new dischargers annually, with 364 temporary and long-term permit approvals in 2019.

The Sanitation Districts, as of 2019, oversees 378 CIUs, 945 SIUs, and 1,552 other industrial dischargers. Table 4-6 summarizes the CIUs in operation as of 2019.

Table 4-6. Sanitation Districts CIUs (2019).

EPA Categorical Regulation	Number of Sampling Locations[a]	EPA Categorical Regulation	Number of Sampling Locations[a]
Aluminum Forming	11	Nonferrous Metals Manufacturing	2
Battery Manufacturing	4	Organic Chemicals, Plastics, and Synthetic Fibers	6
Centralized Waste Treatment	13	Paving and Roofing Materials	1
Coil Coating	5	Pesticide Chemicals Manufacturing	3
Copper Forming	0	Petroleum Refining	11
Electrical and Electronic Components	9	Pharmaceutical Manufacturing	18
Electroplating[b]	15	Porcelain Enameling	0
Feedlots	1	Pulp, Paper, and Paperboard Manufacturing	8
Integrated[c]	42	Rubber Manufacturing	3
Iron and Steel Manufacturing	4	Soap and Detergent Manufacturing	0
Metal Finishing[c]	191	Steam Electric Power Generating	5
Metal Molding and Casting	3	Transportation Equipment Cleaning	7
Nonferrous Metals Forming	4		

[a] For most "sample locations," there is only one site. However, some sites have more than one location, so the number of sites is less than the number of sample locations.
[b] Electroplating is a potential source of both PFAS as well as metals like chromium and nickel. "Electroplating" is an older CIU category, and a lot of electroplating facilities could be categorized as "metals finishing." PFAS is currently not regulated by EPA in either of these industrial categories (USEPA 2021e, USEPA 2021d).
[c] More than one regulation applies at the same discharge location.

The amount of industrial discharge, as a percentage, varies substantially depending upon the sewershed and receiving treatment plant, as shown in Table 4-7.

Table 4-7. Sanitation Districts Treatment Plants and Flows (2019).

Treatment Plant	Capacity (mgd)	Average Flow (mgd)	Industrial Flow (mgd)	% Industrial Flow
JWPCP	400	259.56	43.87	16.9
La Canada	0.2	0.072	0.001	1.3
Lancaster	18	13.44	0.52	3.9
Long Beach	25	8.41	0.67	8.1
Los Coyotes	37.5	18.63	2.65	14.2
Palmdale	12	8.05	0.10	1.2
Pomona	15	5.05	0.23	4.6
San Jose Creek East	62.5	31.67	3.10	9.8
San Jose Creek West	37.5	19.37	0.54	2.8
Saugus	6.5	4.65	0.04	0.9
Valencia	21.6	13.69	1.3	9.5
Whittier Narrows	15	8.11	1.1	13.6[a]
Total	**650.8**	**390.70**	**54.12**	**13.9**

[a] Maximum value shown. Typically the industrial contribution percentage is significantly lower.

The agency was one of the first in the nation to develop local limits as part of its pretreatment program, starting with 11 toxic parameters in 1975, designated as "Phase I" limits and shown in Table 4-8. While developed back in 1975, these limits are periodically reviewed and remain protective of the Sanitation Districts' wastewater collection and treatment system. The Phase I list of local limits is supplemented by categorical and industry-specific limits on facilities, such as oil refineries, oil producing fields, CWT facilities, industrial laundries, landfills, and groundwater cleanup operations. Phase I limits are also supplemented by WRP-specific limits that are of particular importance to specific water reclamation plants, for example efforts to control TDS, chloride, and selenium.

Table 4-8. Sanitation Districts' Phase I Local Limits.

Contaminant	Industrial Wastewater Effluent Limitations (mg/L)[a]
Arsenic	3
Cadmium	15
Chromium (Total)	10
Copper	15
Lead	40
Mercury	2
Nickel	12
Silver	5
Zinc	25
Cyanide (Total)	10
Total Identifiable Chlorinated Hydrocarbons[b]	Essentially None[c]

[a] Maximum allowable concentration at any time
[b] Total Identifiable Chlorinated Hydrocarbons comprise: aldrin and dieldrin; chlordane (cis & trans), trans-nonachlor, oxychlordane, heptachlor, and heptachlor epoxide; DDT and derivatives: p,p' and o,p' isomers of DDT, DDD, DDE; endrin; HCH: sum of alpha, beta, gamma, delta isomers of hexachlorocyclohexane; toxaphene; polychlorinated biphenyls
[c] Limit is to be below detectable levels, approximately 10 µg/L.

The Sanitation Districts approach to local limits is flexible, allowing for different methods to address a particular challenge. Considerations for broad, industry-specific, or discharger-specific local limits includes:

- Broad local limits are applied to all dischargers
- Industry-specific local limits are developed where needed (e.g., toxic organics for laundries, selenium limits for petroleum refineries)
- Evaluation of mass loading, putting limits upon large dischargers of a particular contaminant while not placing limits upon smaller dischargers
- Other controls/solutions
  - In some cases, a discharge must be maintained, even if problematic. For example, a high TDS waste stream was redirected past the San Jose Creek WRP into the sewer line to the JWPCP which could better handle the higher TDS.
  - In other cases, discharges can be banned, such as the banning of self-regenerating water softeners in the Santa Clarita WRP service area.

The Sanitation Districts have authority to recover costs from industrial dischargers.

4.6.4 CWT Facilities

CWT facilities are regulated under 40 CFR 437 and managed under conventional pretreatment programs. Due to some challenging and hazardous events at a CWT in the City of Oxnard in 2015, an updated CWT BMP was developed and endorsed by the California Association of Sanitation Agencies (it should be noted that LACSD have had limits and BMPs for CWTs and other industries dating back to the 1980s). The Sanitation Districts were a part of the team that developed the updated CWT BMP. Key elements of the CWT BMP include:

- Waste Receiving Requirements: including manifests for haulers, testing of hauled waste before disposal, prohibition of specific activities, and allowance for random sampling.
- Treatment Requirements: treatment meeting EPA standards under 40 CFR 437, emergency shutoff, treatment reliability and redundancy, prohibition of holding tanks for dilution, and recording of treatment system operations details.
- Effluent Discharge and Sampling Requirements: batch tanks continuously mixed, sampling and analysis before discharge required, reprocessing if necessary.
- Recommend Certification and Documentation Requirements: requirements for certifications, plans, procedures, operation and maintenance (O&M), treatment system details, documentation of all waste haulers, and testing and monitoring requirements.

The Sanitation Districts receives waste from a number of centralized treatment facilities, noting their names are intentionally withheld from this document:

- CWT 1 (processes ion exchange resin regenerations)
- CWT 2 (truck cleaning and organics)
- CWT 3 (hazardous waste and industrial wastewater)
- CWT 4 (oils)
- CWT 5 (wastewater metals, oils, organics)
- CWT 6 (metals treatment and recovery)
- CWT 7. (oils treatment and recovery)
- CWT 8 (oils and organics)
- CWT 9 (organics)

The CWT facilities are not uniformly distributed across the different LACSD WWTPs, for example there is one that discharges to San Jose Creek East, but none to Pomona, San Jose Creek West, or Whittier Narrows. CWT facilities have clear acceptance criteria, but there are constant challenges because waste can come from several sources and fully characterizing a mixed waste stream is not possible. The Sanitation Districts analyze for substances that have permit limits and others that may cause concern, but this may not capture all contaminants in a waste stream. Importantly, there may be contaminants which require the CWT to provide a service to treat those concentrated waste streams prior to disposal in the collection system, removing the burden of treating a more diluted waste once the contaminant is blended with other effluents at a WWTP.

4.6.5 Hauled Wastes

The Sanitation Districts receive hauled waste at four liquid waste disposal stations within its service area for the acceptance of portable toilet, septic tank, cesspool, and trailer holding tank wastes of domestic origin in compliance with 40 CFR 403.5(b)(8). Industrial wastes are also accepted at these locations if the generator has obtained an industrial wastewater discharge permit for that purpose, if the material has been certified as non-hazardous, and if its disposal at these stations is in the best interest of the Sanitation Districts. The Sanitation Districts do not operate RV disposal facilities, as there are private locations that are available for the disposal of RV wastes. An RV disposal station permit program has been implemented to prevent the discharge of industrial and hazardous wastes at these facilities. They are required to be secure with locking cover or gated locked property. They have signage stating that hazardous waste cannot be dumped. These facilities are inspected at least annually.

Waste haulers must obtain a permit prior to discharge, one for each vehicle. The permit details information on the hauler and the vehicle. As of 2019, there are 177 haulers and 488 permitted trucks. A manifest is collected with each disposal event which details the volume and type of waste, which is then subsequently checked by a Sanitation Districts employee for pH, TDS, color, floatables, and odor. Wastes with pH or TDS readings outside of normal ranges are subjected to further reexamination. Loads may be rejected pending investigation and results. Periodically, samples are taken from hauled loads for pH, COD, TSS, and heavy metals, at a frequency of approximately 4 percent of hauled wastes.

4.6.6 Interagency Agreements

The Sanitation Districts collect sewage from 78 cities. In each of those locations, new businesses enter and leave the market. The Sanitation Districts must have close collaboration with the planning departments in each of these cities. Each City has designated staff that manage all the permits and also may add additional local requirements, resulting in a jointly issued permit. There is mixed responsibility for the sewer collection systems with the various partners as some cities contract with Los Angeles County (but not the Sanitation Districts). The Sanitation Districts' lines are the regional interceptors, with a few exceptions.

Within this large service area, not every business needs a permit. The need for a permit is based upon the type and volume of discharge.

4.6.7 Enforcement Response Plan

The Sanitation Districts works to minimize enforcement actions through a rigorous inspection program, which includes:

- 25 field inspectors, including day and night shift inspectors.
- Extensive field kits and dedicated vehicles to allow for working in the field.
- Data management system for remote entering and recording of inspection data.
- In 2019, the Sanitation Districts conducted 9,299 inspections and performed 3,670 field samples.

Compliance for industrial dischargers is based upon a combination of routine sampling by the Sanitation Districts, surveillance sampling by the Sanitation Districts, and self-monitoring by the industrial dischargers. Enforcement action is initiated against noncompliant users in accordance with the Sanitation Districts ERP guidelines. A brief summary of the enforcement steps utilized by the Sanitation Districts are:

- Notice of Violation is issued.
- A follow-up letter is sent, requiring written response in 30 days that addresses the causes of the violation, the corrective actions which will be taken to prevent reoccurrence, and the date those corrective actions will be completed.
- The response sent by the industry is reviewed.
- A follow-up inspection and/or sampling conducted by the Sanitation Districts.

Each subsequent violation leads to escalation of enforcement action, which considers:

- Type, severity, number, and duration of the violation.
- Impact of the violation on the Sanitation Districts' wastewater collection system, the public and environment.
- Compliance history of the industrial discharger.
- Good faith effort of the industrial dischargers to return to compliance.

Continued noncompliance results in a "Stage 2 NOV" which establishes a mandatory compliance meeting and a compliance schedule, typically resulting in the industrial user conducting intensive self-monitoring if the citations were for numerical violations. Further noncompliance may result in the Sanitation Districts referring the discharger to the Federal Environmental Crimes Task Force or the District Attorney's Office for criminal prosecution or civil action.

To reduce IUs out of compliance, the Sanitation Districts hold workshops for industrial dischargers that have compliance challenges. These workshops educate the dischargers on steps to take to come into compliance.

4.6.8 Monitoring Program

The Sanitation Districts' monitoring program includes both inspection and sampling by the Sanitation Districts and sampling by the industry. Not all industries are required to sample their effluent. As part of the industrial discharge permitting process, a determination on sampling requirements (parameters and frequency) is made based upon the type of industrial process, the anticipated wastewater characteristics, and the receiving water reclamation plant (and water reuse applications). SIUs and CIUs are required to self-monitor at least semi-annually and the Sanitation Districts monitor these facilities at least annually. Nonsignificant industrial users may be required to self-monitor and the Sanitation Districts may sample these facilities when needed (usually for surcharge purposes). As of 2019, 1,012 dischargers are required to perform self-monitoring.

Self-monitoring requirements may include pH, TSS, COD, dissolve sulfides, and federally regulated contaminants. Details include:

- The Sanitation Districts' IW Inspectors collect grab samples in conjunction with onsite inspections of industrial equipment and wastewater sources to confirm compliance with the Wastewater Ordinance.
- Sampling efforts may be done as part of:
  - Surveillance Monitoring: specialized sampling upstream and downstream of suspect industrial dischargers, which can be used as part of enforcement actions.
  - Evidence Sampling Procedure: compliance monitoring of CIUs that may be offered as court evidence in the prosecution of violators.
  - Self-Monitoring by Industries: as part of permitting, some industries are required to perform self-monitoring. A percentage of self-monitoring reports are reviewed by Sanitation District staff for accuracy.

  - Surcharge Sampling: sampling used, in combination with self-monitoring results, to set fees.
- In 2019, a total of 1,942 grab and 2,760 routine composite samples were obtained during the year.

4.6.9 Potable Reuse Water Quality

To assess the effectiveness of the source control program, and as required as part of potable reuse permit requirements, the Sanitation Districts track the concentrations of all state drinking water standards (MCLs, SMCLs, NLs) as well as contaminants of emerging concern (CECs) at the WRPs that are part of potable reuse projects (Pomona, San Jose Creek East, San Jose Creek West, Long Beach, and Whittier). Regarding the CECs, samples are taken for 50 different CECs in the influent and effluent of each WRP twice annually. Compliance with drinking water requirements (e.g., MCLs) are based upon annual average water quality. Results demonstrate the reduction of most regulated contaminants across treatment. Though on occasion, WRP effluent values are greater than regulatory targets, noting that permit compliance is after percolation of the treated water, not the WRP effluent.

For those contaminants that are sufficiently high in the WRP effluent, the Sanitation Districts reviews mitigation measures through the wastewater treatment process and focused source control efforts to reduce contaminants below regulated levels. One example is NDMA, which has a drinking water NL of 10 ng/L but is often above this number in the effluent from most WRPs. While NDMA can be formed due to chloramination or ozonation, some of the larger NDMA values are due to industrial discharges. Greater than 1,000 samples of NDMA were collected in the collection system, and the data indicated that metal finishing facilities and textile-dyeing operations sometimes contained NDMA. Centralized waste haulers, anti-freeze, and some specific root killers were also shown to have high NDMA concentrations. Other contaminants that are being evaluated by Sanitation Districts staff, due to both consistent and inconsistent detections, are Tert-butyl Alcohol, 1,2,3-Tricholoropropane and PFOA. Regarding the first two, the Sanitation Districts are conducting sampling of some industrial sources but have not yet identified any. Regarding PFOA, the Sanitation Districts are sampling and reviewing sources and considering if any limits need to be imposed in the future.

4.6.10 Outreach

The Sanitation Districts maintains an extensive outreach campaign. Examples of that outreach by the Sanitation Districts are included below:

- New industries are provided with a booklet entitled "Information and Instructions for Obtaining an industrial wastewater discharge permit."
- Sponsorship of the Industry Advisory Council, which is a forum to bring together industry, utilities, and regulators with a focus on pollution prevention, resource conservation, and sustainable development.
- Issuance of Certificates of Recognition to many SIUs, including 391 certificates in 2019 for being in full compliance in 2018.
- Implementation of a FOG program to control grease from restaurants and food service establishments. The program includes a training program for local agencies (e.g., the

various cities within the Sanitation Districts' service area).

- Implementation of a water softener rebate program, chloride reduction program, within specific sewersheds.
- Collaboration with the California Air Resources Board to reduce perchloroethylene, methylene chloride, and trichloroethylene, including banning use in dry cleaning and consumer products in the coming years.
- Implementation of No Drugs Down the Drain program, as detailed in LACSD 2022.
- Contribution to the California Product Stewardship Council and the Product Stewardship Institute, allowing the Sanitation Districts to participate in pharmaceutical disposal.
- In response to the USEPA's Dental Office Category, the Sanitation Districts have contacted 3,200 dental offices to provide information about the new rule and the requirements for certification.

4.6.11 Future Potable Reuse Using JWPCP Effluent

The next step for water reuse with the Sanitation Districts is the use and purification of effluent from the Carson JWPCP, which takes residuals from most of the upstream WRPs. Over the last several years, the Sanitation Districts have partnered with the Metropolitan Water District to construct and operate a membrane bioreactor (MBR), RO, and UVAOP demonstration facility, called the Advanced Purification Center (APC). The APC utilizes all full-scale components and is testing the system in two modes, as a tertiary MBR (taking secondary effluent) and as a secondary MBR (taking primary effluent). Some early thinking about source control for this future project includes:

- The JWPCP, because it takes residuals from most upstream WRPs (e.g., solids), by default incorporates the rigorous source control programs from those WRPs. These residuals are anticipated to settle out in the primary treatment step at the JWPCP and thus are not deemed problematic.
- The JWPCP's immediate service area, compared to the upstream WRPs, has a higher percentage (by flow) of industrial dischargers. These dischargers are well understood and regulated and the contaminants discharged from those industries are known and controlled.
- The ongoing APC testing is examining contaminant levels and reduction across treatment, thus determining whether there are any challenging contaminants that must be addressed, both in the advanced treated water and in the concentrate from the RO process. Based on prior examples and authority, the Sanitation Districts could implement specific local limits to address any contaminant challenges, as needed.

4.6.12 ESCP Cost and Resources

The Industrial Waste Program team at LACSD is robust, currently consisting of 65 full time employees with an operating budget around $15 million per year. No new staff positions are planned for the implementation of the ESCP, though it is acknowledged that some staff time will be needed to support aspects of the ESCP, particularly, the analytical burden. LACSD maintains a budget of approximately $150,000 per year to support the ESCP, which includes both labor and laboratory costs for the additional sampling. Current staff have also been tapped to support source control investigations for NDMA, PFOA and other contaminants.

4.7 Hampton Roads Sanitation District, Virginia

Contact: Mike Martin (mmartin@hrsd.com)

Source Control Program Status: Currently implements a robust pretreatment program for all of their 17 WWTPs. The HRSD has an ESCP specific to Nansemond Treatment Plant (NTP) where the Sustainable Water Initiative for Tomorrow (SWIFT) Research Center (SRC) is located. Sampling efforts are occurring at other WWTPs where SWIFT will be implemented in the future.

Potable Reuse Project: The HRSD SRC will add multiple AWT processes to select HRSD WWTPs to produce a highly treated water (SWIFT Water™) that exceeds drinking water standards and is compatible with the receiving aquifer. Secondary effluent from up to seven of HRSD's existing treatment facilities will be advanced treated and SWIFT Water™ will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. At full-scale, HRSD intends to recharge up to 100 mgd of SWIFT Water™ that will significantly reduce the nutrient load to the sensitive Chesapeake Bay and provide benefit to the region by limiting saltwater intrusion, reducing land subsidence, and providing a sustainable source of groundwater, a necessity for continued economic expansion in the region.

The 1 mgd SRC began operating in May 2018 and has recharged more than 400 MG of water to the Potomac Aquifer as of January 2021. The first full-scale SWIFT facility is planned to be online in 2025 and will be located at the James River Treatment Plant (JRTP).

HRSD has historically maintained a robust pretreatment and pollution prevention (P3) program that manages the IUs and complies with the NPP. The program includes:

- A "One Water" approach, considering the various needs of potable reuse, non-potable reuse, biosolids recovery, biogas recovery, and nutrient recovery.
- 17 WWTPs that operate mostly independently.
- Service for 1.7 million customers.
- 145 mgd average flow; 249 mgd total WWTP capacity; 54 mgd of non-potable reuse.
- 175 total permitted industries (57 significant and 19 categorical).
- 15 mgd total permitted flow from industries.

As the SWIFT program has developed within HRSD, so has the P3 program. Initial efforts included the identification of contaminants that were relevant to human health, including the EPA regulated contaminants and a suite of unregulated contaminants. Sampling for these groups of contaminants began at each of the candidate WWTPs and at the discharge of industries at least 1 year prior to the SRC coming online. This provided a robust data set for the contaminants that were expected to be a challenge for SWIFT treatment and thus would need to be a focus for the P3 team.

The project team's interview, and this case study, differs from the other case study efforts, focusing on HRSD's large sampling effort as it pertains to SWIFT, an evaluation of how contaminants are addressed through treatment, and then corrective action with industrial dischargers, as needed.

After the SRC came online in 2018, the P3 team's efforts expanded to supporting operation of the SRC. When challenging contaminants were identified at the SRC, the P3 team would review sampling data to identify if any industries were significant contributors, on a load basis, and then work with the industries on identifying a path forward. P3 is also supporting planning efforts for the full-scale facilities. The following provide key areas of focus of the P3 team during the first several years of operation of the SRC and in planning for the other facilities.

4.7.1 Bromide

Bromide levels are high in many of HRSD's WWTPs, typically ranging between 0.4 and 1.2 mg/L. This presents a problem with HRSD's selected treatment train as ozone oxidizes bromide to bromate, a regulated contaminant. When the SRC started up in 2018, the bromate formation was higher than expected. Prior to startup of the SRC, sampling by the P3 team had shown that a significant amount (greater than 50 percent) of the NTP influent bromide came from one SIU, a landfill. Once bromate was identified as a challenge, the P3 team quickly worked with the landfill to pump and haul the leachate to a different service area so that a baseline influent bromide level at NTP could be established. As shown in Figure 4-4, over a 1-month period the influent bromide decreased from 0.5-0.6 mg/L to 0.2 mg/L. It is interesting to note that it appeared that the collection system provided significant attenuation as it took more time than expected for the bromide levels to decrease.

This lower bromide concentration was acceptable for SRC operation as bromate was well below the regulated limit of 10 µg/L. The SWIFT team then worked to establish a relationship between influent bromide concentration and bromate formation, as shown on Figure 4-5 (Hogard 2019). This research provided the basis to allow landfill leachate flow to target an influent bromide concentration of 0.5 mg/L. The P3 team then worked with the landfill to establish a consistent flow rate that achieved this level of influent bromide. HRSD is currently working toward a longer-term solution, potentially pumping the landfill leachate out of the NTP service area to a WWTP where SWIFT will not be implemented. This example demonstrates the coordination and communication needed to find a solution that worked for both HRSD and the landfill.

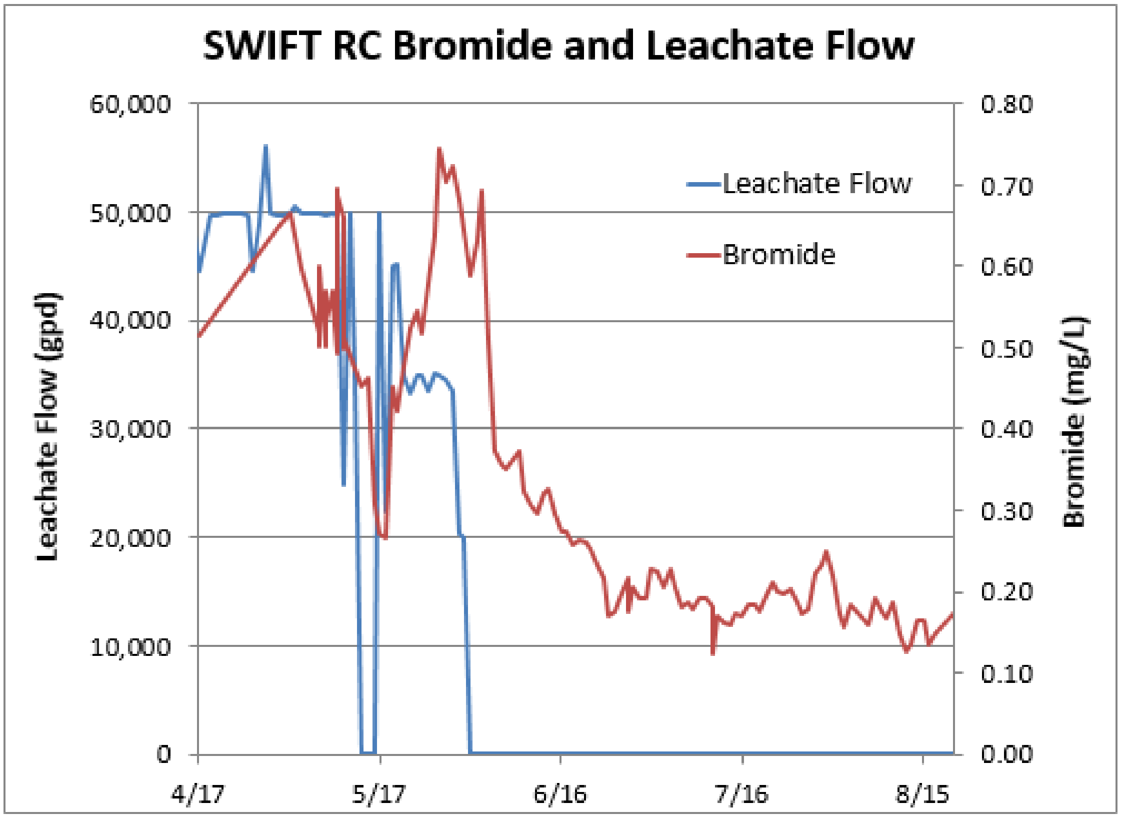

Figure 4-4. SRC Bromide and Leachate Flow.

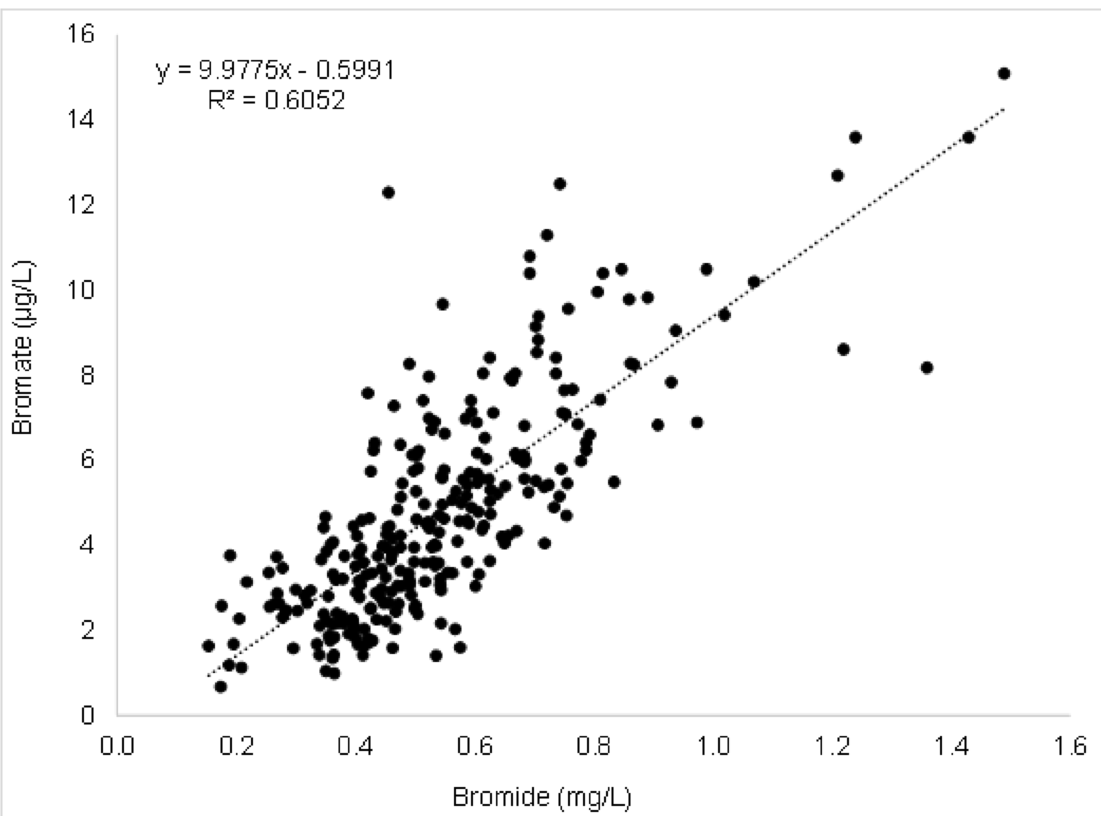

Figure 4-5. SRC Influent Bromide and Bromate Formation.

4.7.2 1,4-Dioxane

Background 1,4-dioxane levels are high in most of HRSD's service areas, with typical values in the range of 0.8-1.3 µg/L. The SWIFT program has an unregulated water quality goal of 1 µg/L and is closely monitoring state and federal regulations in anticipation of a lower limit. The SRC achieves modest removal of 1,4-dioxane and HRSD is currently researching and piloting ways to optimize removal with the selected treatment processes. In parallel, the P3 team has been reviewing data to identify significant contributors.

At JRTP, the location of the first full-scale facility, P3 identified an industrial user, also a landfill, that contributes nearly 50 percent of the influent 1,4-dioxane. The high 1,4-dioxane values at JRTP motivated HRSD to consider upgrading the SWIFT UV reactors to UVAOP to achieve good 1,4-dioxane removal. To avoid this costly treatment alternative, HRSD is investigating removal options at the landfill prior to discharge into the collection system. The landfill already had two moving bed bioreactor (MBBR) trains as pretreatment for their discharge. In 2020 the P3 team initiated a pilot study to determine whether cometabolite addition (tetrahydrofuran [THF]) upstream of the MBBR could help develop biology to biodegrade the 1,4-dioxane. Preliminary results are shown in Figure 4-6 and suggest there will be significant removal in the MBBR, up to 90 percent, which will reduce the influent JRTP 1,4-dioxane concentration by an estimated 40 percent. This is a significant achievement as it will avoid the installation of costly (capital and operational) treatment specific to 1,4-dioxane at JR SWIFT.

While preliminary, these results offer a promising example of how providing treatment at the industry itself can save significant cost compared to treatment at the WWTP or advanced treatment facility. Clear communication with the landfill team was essential in working to provide a mutually beneficial solution. HRSD is currently supporting the pilot effort in a cost-share agreement but it is anticipated that the landfill will pay for the capital upgrades and operational costs required to operate the system at full-scale. HRSD has not implemented a site-specific limit for 1,4-dioxane and will wait until after the improvements are made to determine whether such a limit is needed.

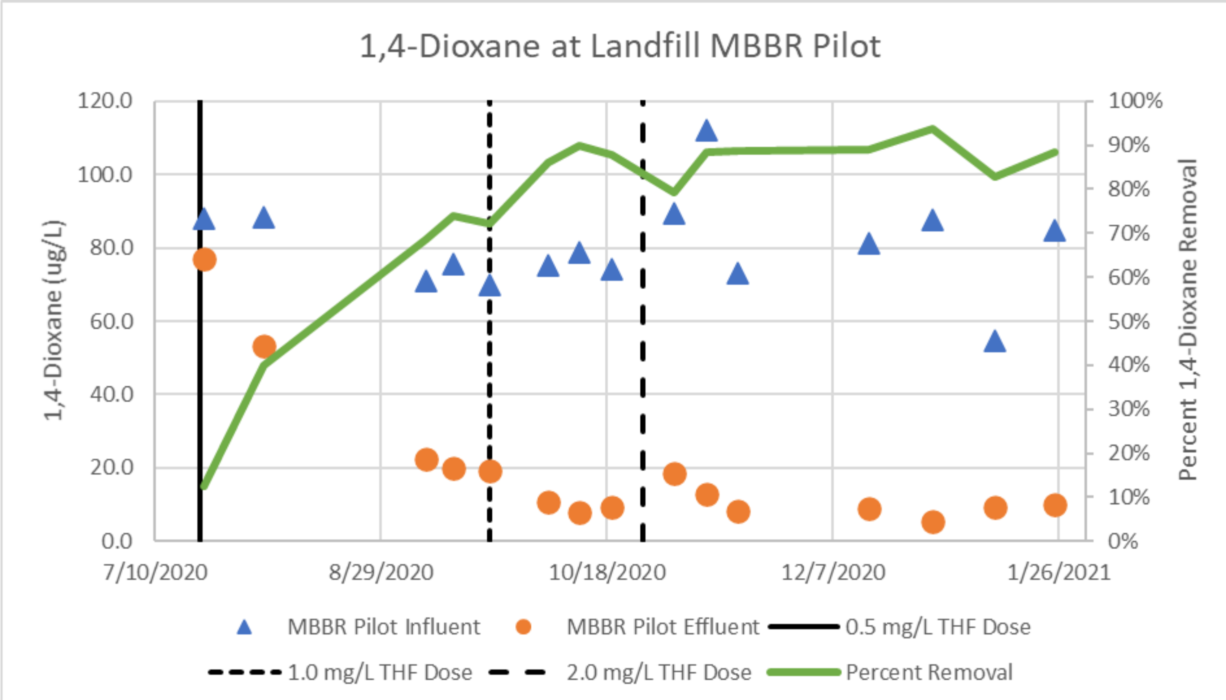

Figure 4-6. 1,4-Dioxane Removal at Landfill MBBR Pilot.

4.7.3 Acrylamide

Acrylamide is an EPA regulated contaminant. It is unique in that it does not have a listed MCL, rather it has a treatment technique goal. As there is acrylamide in polymer often used in water and WWTPs, the EPA allows for up to 1 mg/L of polymer dose with a maximum acrylamide concentration of 0.25 percent. Therefore, any acrylamide measured above that level would exceed the MCL.

The SRC does add a flocculation aid polymer that has a small acrylamide concentration and there is also polymer added at the NTP. Both polymer products are NSF61 certified and are dosed in the allowable range. However, acrylamide was detected in the SWIFT Water™ in 2018 and HRSD began investigating potential sources. They quickly identified this was not due to the polymer they were adding at NTP or at SWIFT so they began looking for other sources. The P3 team knew that one of NTP's permitted industries was a chemical manufacturing company that produced a concentrated acrylamide product. A series of sampling campaigns identified a significant amount of acrylamide in the industrial discharge, resulting in the influent acrylamide concentration at NTP several orders of magnitude higher than the MCL. While the biological processes at NTP and SRC provide excellent removal of readily biodegradable contaminants like acrylamide, the magnitude of the influent concentration and its variability proved enough to break through the treatment processes.

After identifying the cause of the influent concentrations, HRSD worked with the industry over the course of several months to identify a site-specific limit for this industry (HRSD did not apply an acrylamide limit to all permitted industries). HRSD calculated the limit based on a continuous, acceptable level of influent acrylamide that would minimize risk of causing a regulatory exceedance, as described in the text box below. The permit was finalized in Oct 2020 and has a daily load limit for acrylamide based on composite daily sampling and monitoring. As of March 2021, there have been no permit violations and the industry has been able to adjust their operations so that their discharge complies with the permit without needed to pump and haul or perform additional treatment.

Setting a Site-Specific Limit for a Permitted Industry

This text box describes how HRSD set a site-specific limit for acrylamide for a single permitted user after detecting acrylamide in the SWIFT Water™ and identifying an industry that discharges a significant amount of that contaminant on a load basis.

Identification of target influent acrylamide concentration to SWIFT: 0.1 ug/L was selected as the allowable influent acrylamide concentration to the advanced treatment process. This is the detection limit for acrylamide and was selected by HRSD so that the theoretical acceptable amount of acrylamide would be below the level of detection.

Estimate of removal across NTP: HRSD performed sampling at the NTP influent and effluent and also performed sequencing batch reactor (SBR) sampling to estimate the removal across the WWTP process. The data suggest good removal as acrylamide is highly biodegradable. HRSD conservatively selected the fifth percentile of removal, which was 95.8%.

Allowable NTP influent load: Taking the allowable NTP effluent concentration (0.1 ug/L), the removal across NTP (95.8%) and the average NTP flow (18 mgd), the allowable acrylamide influent load is calculated at 3,575 lb/day.

Adding a safety factor: Only limited data were available for these calculations and the data were highly variable. The average to maximum factor was over 13, suggesting highly variable influent NTP concentrations. There were only 20 paired data points available to calculate the NTP removal, so an additional safety factor of 2.5 was added to account for the small data set. Applying these two safety factors decreases the allowable acrylamide influent load to 119 lb/day.

Allocating the allowable load: HRSD is not aware of any other industrial, commercial, or domestic dischargers of acrylamide within the NTP collection system and decided to allocate all of the allowable acrylamide load to this single user. This resulted in an effluent discharge limit of 119 b/day for this permitted industry. No other industries received an acrylamide limit.

4.7.4 Sequencing Batch Reactors

The SWIFT treatment process uses multiple barriers to organic chemicals to reduce the SRC influent TOC from around 8 mg/L to below the regulated limit of 4 mg/L prior to recharge. Higher influent TOC is a risk to the SWIFT program as it will result in more frequent, and costly, GAC regeneration. HRSD is therefore motivated to identify ways to decrease the influent TOC, particularly for the recalcitrant, difficult to remove, fraction of TOC.

NTP provides significant organics removal; around 90 percent of the influent COD is removed in the 5-stage Bardenpho process. But HRSD hypothesized that the majority of the remaining 10 percent of COD is recalcitrant. HRSD had already set up a series of sequencing batch reactors (SBRs) to research and optimize secondary treatment at NTP and its other WWTPs. To understand the impact of different industries on the SRC influent TOC, HRSD began SBR testing where discharge from specific industries was added at increasing values and compared to a control. The control was able to reasonably represent NTP removal but the SBRs that received the industrial discharge showed higher effluent COD values. In particular, addition of landfill leachate to the SBRs indicated that none of the COD from the landfill was removed from the

SBR. Some of the data even suggested that addition of the landfill leachate inhibited the removal of other COD, although there were not enough data points to claim this with certainty.

While this SBR has not resulted in direct action or the implementation of site-specific limits, it has helped HRSD understand major sources of organics that make their way through the WWTPs. If needed in the future, HRSD will be able to work with these industries on a solution that helps them better achieve the SWIFT TOC limits.

4.7.5 Online Monitoring

HRSD has been strategic about how it uses online monitoring in its collection systems. Rather than jump in with comprehensive online monitoring installations that would be costly and potentially unnecessary, HRSD is strategically identifying how online monitoring can be implemented to help identify specific challenges. HRSD's lessons learned and case studies in online monitoring are provided below.

4.7.5.1 Salinity

Much of HRSD's service area is at low elevations, very close to sea level. The primary rivers that currently receive treated wastewater are tidal, rising and falling both daily and monthly, and are high in salinity as they are a mix of surface water and sea water. The background TDS at HRSD's WWTPs ranges from 500-800 mg/L at the higher elevation facilities to 1,000-1,500 mg/L at the lower elevation facilities. During high tide and/or storm events, the TDS can increase significantly, varying on the event and on the facility.

TDS and bromide display a strong correlation in HRSD's service area, so high TDS events also bring high bromide into the collection system which provides a challenge for the ozone oxidation process. HRSD has installed a series of conductivity analyzers in the collection systems of these lower elevation facilities to better understand the correlation between tide and conductivity and identify portions of the sewershed that are more susceptible to inflow. This provides a characterization of how often bromide levels would be too high for SWIFT treatment. In addition to online monitoring, during high tide events the P3 team has been dispatched to measure conductivity levels in the field, moving upstream from the WWTPs to find the major inflow areas. This process has identified many areas that have either already been fixed or will be fixed in the future. Analysis of progress will identify if this systematic approach will be enough to help HRSD consistently meet TDS (and bromide) targets or if additional action is needed.

4.7.5.2 NTP Upset Events

Since the SRC was put into operation in 2018, there have been monthly upset events, that appear to be relatively consistent, where a slug of sewage high in nutrients and organics enters NTP for a 4 to 8-hour period. This often brings the SRC influent TOC up from typical values around 8 mg/L to 15-20 mg/L and affects NTP performance for 24-48 hours. During these periods the SRC must be taken offline until the event has subsided as the process is unable to meet the finished water TOC target.

WWTP influent sampling during the upset events shows that both COD and total phosphorous (TP) spike during the 4-8 hour period but HRSD had been unable to identify the source of the upsets through dialogue and communication with industries. Starting in October 2020, HRSD installed an online orthophosphate (OP) analyzer at a strategic area in the collection system to see if they could systematically detect the source of the upsets. There were many initial challenges in getting reliable results from the OP analyzer but HRSD was able to troubleshoot the analyzer challenges and maintain it long enough to identify and eliminate the cause of the upset events. While this does not represent widespread adoption of collection system monitoring, it provides an example of strategic implementation to target specific challenges.

4.7.5.3 Additional Online Monitoring Experience

HRSD has experimented with online monitoring for several different parameters, including and in addition to conductivity and OP. A summary of their experience, challenges, and successes are provided here.

- Many of HRSDs service areas consist of force main sewers, rather than gravity mains. HRSD has tried many different approaches to install analyzers on force mains but it has proved quite challenging to install directly into the pressurized piping and to pump the analyzer effluent back into the pipe. While they have had success monitoring in the wet wells of pump stations, installing sensors in force mains is an ongoing challenge.
- HRSD has considered adding online analyzers in the piping for industries that only discharge intermittently. Will the analyzers they need to install be able to operate during intermittent wet and dry periods?
- Often when online measurement is needed, it is part of an investigation where the analyzer will be moved throughout the collection system in order to find a specific challenge. Therefore, it is often not worth a big investment to install temporary analyzers.
- The time and labor investment to keep online analyzers up and running can often outweigh the value of the monitoring and difficult cost-benefit decisions need to be made in many situations.

4.7.6 Effect of Unannounced Sampling on Violations

While each permitted industry performs the majority of their compliance sampling, HRSD also conducts both announced and unannounced sampling at select industries. Data analysis was conducted to determine whether more violations were detected during unannounced sampling and the results are shown in Table 4-9. More than 1,400 sample events were reviewed and the percentage of violations during announced sampling (2.7 percent) and unannounced sampling (2.6 percent) were very similar. This suggests that industries do not change operation in advance of announced sampling and that additional unannounced sampling may not be valuable for HRSD.

Table 4-9. Effect of Unannounced Sampling on Violations.

	Announced	Unannounced
# Facilities	20	32
# Sample Events	971	430
# Violations	26	11
% Violation	2.7%	2.6%

4.7.7 Additional Source Control Program Information

As discussed, HRSD had a robust P3 program prior to embarking on enhanced source control as part of its SWIFT program. The following list provides information on different features, challenges, and successes of the P3 program.

- It has been best to get ahead of future issues; HRSD tries to start working with industries two or more years before implementing site-specific limits to allow for dialogue, data collection, and resolution. The earlier the better!
- HRSD has historically not had much pushback when implementing site-specific limits because they were typically in response to federal regulations to protect the Chesapeake Bay. Having strict federal backing as the reason for limits has helped in discussions with industries.
- HRSD has found the most success when they work directly with the industries to better understand the issues. An open and up-front approach has worked well for them and the industries appreciate being involved in the discussion. This has recently included many tours to the SRC so that industries can understand the SWIFT process and how they are connected to these big, regional water solutions.
- HRSD is a regional agency and as such, does not have a single municipal counterpart; rather, there are 18 different localities that contribute to HRSD's collection system. This has made it difficult to set up a single, streamlined system to account for new industries. To counter this, HRSD has set up a system whereby their P3 is notified whenever a new commercial or business account is added and then P3 can further investigate. The P3 team has also taken upon itself to review all accounts registered as residential that consume more than 1,000 gallons per day. This has led P3 to identify many businesses that were mislabeled as residential accounts by the locality, whether intentional or unintentional.
- HRSD has site-specific limits for many industries. BOD, COD, TSS, TP, and total nitrogen (TN) have all been implemented for many permitted industries. Each time HRSD sets a site-specific limit, they use a data-based approach that identifies the allowable load to the WWTP and allocates the influent contaminant load between the permitted industries that discharge each contaminant. This provides a thoughtful approach to what can be a challenging topic and avoids the "heavy hammer" of local limits.
- HRSD recently went through an independent audit of several of its programs and teams and elected to include the P3 program in this audit. The goal of this audit was to make sure the P3 team's actions were transparent and defensible. The audit identified a few areas for HRSD to improve, mostly related to software changes and in how HRSD handles its hauled waste program. This audit resulted in increased confidence in P3's general approach to its permitted industries.
- HRSD has the ability in its rate schedule to apply special rates based on unusual discharge.

This provides a framework whereby if a single industry discharges a significant load of a contaminant that requires additional treatment at SWIFT, HRSD can apply increased rates to the specific industry to account for the additional capital and operational cost to remove the contaminant. This is a tool that HRSD may need to use further down the road.

- HRSD identified three types of industries as the most challenging for them:
  - Landfills: in addition to the anecdotes provided above, it is difficult to know what is going to be in landfill leachate. There are many significant differences between the leachate from different landfills in HRSD's service area and there are significant differences in how to work with the different landfills based on their ownership structure (private vs. public, local vs. national, etc.).
  - Organic Chemicals: some chemical manufacturers run different campaigns at different parts of the year, resulting in inconsistent discharge characteristics. HRSD has set up a system whereby the industry must notify HRSD in advance of a new campaign and HRSD will sample during each new campaign.
  - Meat and Poultry: these industries do not provide major challenges at the WWTP or for SWIFT but can often result in NOx issues in the sewershed and force mains that has been problematic for HRSD.

4.7.8 ESCP Cost and Resources

HRSD's pretreatment team originally consisted of 6 full-time employees. A seventh employee was recently hired, partly to support the ESCP and partly to support other pretreatment activities. HRSD's current annual budget for pretreatment (and ESCP) is around $2.8 million. HRSD estimates that going from pretreatment program to ESCP has cost around $440,000 per year. This includes $90,000 per year for the additional employee, $100,000 per year for the sampling cost at the SRC, and $250,000 per year for background sampling at the other WWTPs. Once SWIFT is fully implemented, the ESCP will encompass seven total WWTPs and is expected to increase in cost once more than one facility is operational.

4.8 City of Palo Alto, California

Contact: Samantha Engelage (Samantha.Engelage@CityofPaloAlto.org)

Source Control Program Status: The City of Palo Alto and the City of Mountain View currently implement a detailed pretreatment program under the USEPA's NPP for the Palo Alto Regional Water Quality Control Plant (RWQCP). An ESCP has not been established.

Potable Reuse Project: Valley Water is a regional water wholesaler located in the south San Francisco Bay Area (headquartered in San Jose California). Valley Water is developing a regional potable reuse program, working with different partners to supply treated effluent for subsequent purification and potable reuse. One potential future partner for Valley Water is the City of Palo Alto. In that example, the project would involve treating effluent from the Palo Alto RWQCP through a new advanced water purification system. The planned use of the estimated 11,000 AFY of advanced treated water is currently for IPR application. However, there is flexibility in the system to accommodate DPR as well.

The City of Palo Alto owns and operates the RWQCP that treats wastewater from the cities of

Los Altos, Palo Alto, and Mountain View, the Town of Los Altos Hills, the East Palo Alto Sanitary District, and the unincorporated area of the Stanford University campus. The service area population is approximately 220,000.

The approximately 20 mgd of average daily influent flow consists of 60 percent from domestic sources, 30 percent from commercial businesses and institutions, and 10 percent from industries. The plant's design flow rate is 39 mgd, but it can treat up to 80 mgd during wet weather conditions.

The City of Palo Alto administers the pretreatment program for all partner agencies except for the City of Mountain View, which administers the pretreatment program for itself. Palo Alto Pretreatment Program staff includes:

- Watershed Protection Manager
- Program Manager
- Associate Engineer
- Senior IW Investigator
- Three IW Inspectors

Mountain View operates a portion of the RWQCP Pretreatment Program. Mountain View's Environmental Protection Division staff includes:

- Manager
- Senior Inspector
- Water Environment Specialist
- Environmental and Safety Protection Inspector

The research team and Valley Water team members met with Palo Alto on November 11, 2020, and May 6, 2021, to collect and analyze Palo Alto source control information.

4.8.1 Sewer Use Ordinance

The cities of Palo Alto and Mountain View each have their own SUOs and ERPs. Palo Alto's SUO, Ordinance No. 5084 of the Palo Alto Municipal Code, is in the process of being revised, and hence this case study provides relevant information for current and future SUO items. The existing SUO establishes the authority of the City to implement state and federally mandated stormwater, pollution prevention, and IW pretreatment programs. Under the proposed revisions, Stormwater, FOG, and waste hauler requirements would be removed from the SUO and placed within their own ordinances. The revisions would also more closely align the City's SUO with the EPA's model SUO. Included in the proposed amendments are provisions that grant additional authority to the Director of Public Works. For example, under provision 16.09.125, the Director is granted authority to perform inspection and sampling of IUs. Included in this provision is the ability of the Director to seek a search warrant through appropriate courts when denied access to a discharger's premises and the ability of the City to install or set up sampling equipment on discharger premises for compliance monitoring. Provision 130 adds several self-monitoring requirements on the IUs and authorizes the Director to require an IU to sample for a subset of toxic organic compounds for TTO monitoring. Provision 135 grants the

Director the ability to authorize an industrial user an optional monitoring waver in which the IU may forgo sampling of a regulated contaminant if the IU has demonstrated that the contaminant is neither present nor expected in the IU's discharge.

The City of Mountain View, as part of their agreement with Palo Alto, must either adopt their own SUO changes or adopt Palo Alto's SUO changes by reference, resulting in matching SUOs for the two cities.

In total, the City's revised SUO allows for a flexible approach to set potable reuse specific IU discharge limits, if needed. The revised SUO also allows for direct monitoring of industrial dischargers, whether that is through grab sampling, composite sampling, or online monitoring. Those future limits and sampling approaches would be applied across the sewershed, including both Palo Alto and Mountain View.

4.8.2 Plant Upsets

In 2019 and 2020, the RWQCP did not experience any discharges from non-domestic users that were suspected of causing plant upset, interference or pass-through.

4.8.3 Local Limits

The City implements local limits to regulate wastewater discharges in its service area and control discharges of conventional and toxic priority pollutants entering the RWQCP. The City of Palo Alto first developed its local limits in 1994.

The local limits evaluation process involves identifying pollutants of concern (POCs) for the RWQCP, including the 15 national POCs that are often found in WWTP effluent and biosolids (according to the 1987 and 2004 EPA Manuals). Additional POCs were selected for limits based on the RWQCP NPDES permit, treatment process inhibition levels, incinerator air emissions standards (40 CFR 503.43), wastewater collection system concerns (corrosion, headspace toxicity, etc.), and categorical pretreatment standards overseeing the City's industrial dischargers. These categories are CFR 40 433.15 and CFR 40 433.17 (metal finishing) and CFR 40 469.18 (electrical and electronic components).

The City's local limits, shown in Table 4-10, are periodically reviewed, and revised as necessary, to respond to changes in RWQCP infrastructure or operations, regulations, or IUs. Such review and potential revision would occur as part of a future potable reuse program, as one example. The limits were last reviewed in 2018. No changes were made to the Pretreatment Program's local limits since 2010.

Table 4-10. Palo Alto RWQCP Local Limits.

Contaminant	Local Maximum Limit (mg/L)	Contaminant	Local Maximum Limit (mg/L)
Arsenic	0.1	Mercaptans	0.1
Barium	5.0	Mercury	0.01
Beryllium	0.75	Methyl Tertiary Butyl Ether (MTBE)	0.75
Boron	1.0	Nickel	0.5
Cadmium	0.1	Phenols	1.0
Chromium, Hexavalent	1.0	Selenium	1.0
Chromium, total	2.0	Silver	0.25
Cobalt	1.0	Single Toxic Organic	0.75
Copper	0.25	TTO	1.0
Cyanide	0.5	Zinc	2.0
Dissolved Sulfides	0.1	Oil and Grease	20
Fluoride	65	Oil and Grease (total)	200
Formaldehyde	5.0	Suspended Solids[a]	3,000
Lead	0.5	Total Dissolved Solids[b]	5,000
Manganese	1.0	pH	5.0-11.0 allowable

[a] Applies to composite samples only. The local maximum limit for instantaneous samples shall be 6,000 mg/L.
[b] Applies to composite samples only. The local maximum limit for instantaneous samples shall be 10,000 mg/L.

The City provides some flexibility to smaller dischargers, understanding that larger IUs contribute much higher mass loadings. For IUs with average daily discharges greater than 50,000 gpd, the limits are one-half of the limit established in the table above, with the exception of limits for copper, mercury, MTBE, nickel, and silver. The City has a set of limits and requirements that provide flexibility to certain categories of industrial dischargers. The local limits for copper established in the table above apply to all IUs except where alternative copper limitations have been established. Alternative copper limitations apply to commercial and industrial wastewater dischargers from specified dischargers or facilities that are components of larger facilities including cooling systems, pools, spas, fountains, boilers, heat exchangers, photographic materials processing facilities, dental facilities, vehicle service facilities, and machine shops. The provisions for alternative copper limitations are found in Section 16.09.060 under the proposed revisions to the SUO.

Local limits for mercury established in the table above do not apply to dental dischargers and are outlined in provision 16.09.240. Dental dischargers are required to submit an annual report for each facility in accordance with the guidelines established by the Director of Public Works. The SUO Section 16.09.240 also requires dental discharges to comply with several requirements involving the operation, maintenance, and monitoring of operations which involve contact and noncontact amalgam. The limit for silver does not apply to photographic material processors. Requirements for photographic material processing facilities, including requirements for silver, can be found in Section 16.09.235. Additionally, the limit for zinc, which is detailed in 16.09.245 does not apply to vehicle service facilities.

4.8.4 Industrial Dischargers

The industries within the collection system service area are tracked and updated in different ways. Mountain View tracks industries through building permits and business registration lists, whereas Palo Alto tracks through building permits and supplements that list via google and field surveys. As of this writing, there are 123 permitted dischargers within the service area including 56 in Palo Alto, 7 in unincorporated Stanford, 55 in Mountain View, 2 in Los Altos, and 3 in East Palo Alto.

Based upon a review of 2019 and 2020 pretreatment program annual reports, there are six CIUs that discharge to the RWQCP:

- Four CIUs within the Metal Finishing Point Source, Category, 40 CFR 433.17
- One CIU within the Metal Finishing Point Source, Category, 40 CFR 433.15
- One CIU that fits within two Categories – Metal Finishing Point Source Category, 40 CFR 433.15, and Electrical and Electronic Component Point Source Category, 40 CFR 469.18

Four other CIUs are noted as having zero process discharge:

- One CIU within the Metal Finishing Point Source, Category, 40 CFR 433.15
- One CIU within the Pharmaceutical Point Source Category, 40 CFR 439.47
- Two CIUs within the Metal Finishing Point Source, Category, 40 CFR 433.17

Two non-categorical SIUs discharge to the RWQCP:

- A closed landfill
- A space research and technology research center

The City of Palo Alto doesn't permit but does regulate dental dischargers, requiring dischargers to submit an annual report for each facility in accordance with the guidelines established by the Director of Public Works. The proposed revised SUO Section 16.09.240 also requires dental discharges to comply with several requirements involving the operation, maintenance, and monitoring of amalgam process elements.

Under the proposed revisions to the SUO, stormwater, FOG, and waste hauler requirements would be completely removed. Separate Stormwater, FOG and waste hauler Ordinances would be created by the Watershed Protection Group to be codified in the Palo Alto Municipal Code.

4.8.5 Interagency Agreements

The City of Palo Alto has jurisdictional agreements with its partners—the cities of Los Altos, Palo Alto, and Mountain View, the Town of Los Altos Hills, the East Palo Alto Sanitary District, and the unincorporated area of the Stanford University campus—that delineate pretreatment program responsibilities. The City of Palo Alto administers the pretreatment program for the entire service area, except in the City of Mountain View. City of Mountain View staff administers most pretreatment program elements in the City of Mountain View with the exception of industrial user and vehicle service facility monitoring, which is performed by RWQCP staff. The roles and responsibilities of each partner agency are outlined in a collection of agreements:

- Contract No. C237 Between the City of Palo Alto and the East Palo Alto Sanitary District, March 11, 1940, as amended.
- Contract No. C869 Between the City of Palo Alto and the Board of Trustees of the Leland

Stanford Junior University, November 30, 1956, as amended.

- Agreement No. 2876 Between the City of Palo Alto and the Town of Los Altos Hills, March 18, 1968, as amended.
- Contract No. C2963 Between the City of Palo Alto, the City of Mountain View, and the City of Los Altos, October 10, 1968, as amended.

While the pretreatment program is multi-jurisdictional, most industrial and commercial dischargers are located within the cities of Palo Alto and Mountain View. The City of Palo Alto regulates one CIU in the East Palo Alto Sanitary District. Palo Alto Pretreatment Program staff conducts sampling and inspections at this facility, creates discharge permits, and issues enforcement actions. East Palo Alto Sanitary District finalizes and issues IW discharge permits.

4.8.6 Enforcement Response Plan

The cities of Palo Alto and Mountain View each have their own ERPs that describe how noncompliance with IU discharge permits, local SUOs, and/or the National Pretreatment Standards are addressed. Palo Alto's ERP was first approved in 1991 with subsequent revisions in 1996, 2002, 2010, 2013, and 2017. No changes were made to the Pretreatment Program's ERP in 2020.

By contract, the partners must maintain equivalent ordinance provisions pertaining to the control of discharges to the sanitary sewer system.

Palo Alto's ERP describes how the City will investigate and respond to instances of discharge noncompliance with the SUO and/or the National Pretreatment Standards. The enforcement and response responsibilities lie with the Watershed Protection Group, which resides within the City's Department of Public Works – Environmental Services Division. The ERP lists the types of noncompliance, the types of enforcement actions (e.g., verbal warnings, warning letters, administrative citations), procedures for issuing compliance orders, Enforcement Escalation Process and timeframes, and special actions for severe noncompliance. In most instances of noncompliance, a series of steps, known as the "Enforcement Escalation Process" will be followed. The process is summarized below.

The focus of the ERPs is on the protection of the WWTP, storm drain systems, local creeks, and the San Francisco Bay. As such, details may need to be adjusted in the future to directly address concerns and actions necessary to protect potable reuse applications.

Under the revised City of Palo Alto SUO, several enforcement items were added to align with the EPA's SUO model more closely. Provision 16.09.080 includes items which grant the Director to use general permits as a control mechanism. The provision also grants the Director authority to decline permit issuance or reissuance in the event of unpaid fees, fines, or penalties. Provision 16.09.260 grants the Director enforcement mechanisms. If an IU is in violation or continues to violate requirements of their individual wastewater requirement, or requirements outlined in the SUO, the Director may issue an order to cease and desist all violations and comply with all requirements. The provision also allows for the complete halt to operations of the IU or termination of the discharge.

In extreme cases when an IU's discharge appears to present imminent or substantial public health or welfare issues, or if the discharge threatens to interfere with the WWTP's operation or endanger the environment, the Director may call for an emergency suspension of any discharge after an informal notice to the IU. Provision 16.09.265 discusses pretreatment charges and fees for reimbursement of establishing and operating the City's Pretreatment Program, which may have implications for the development of a future potable reuse program. In addition to administrative fees, the provision allows for the adoption of fees for monitoring, inspections and surveillance procedures and fees to recover costs associated with enforcement to address discharger noncompliance.

4.8.7 Monitoring Program

The monitoring program involves self-monitoring compliance sampling by IUs, routine unannounced sampling by the City, follow-up sampling by the City (as necessary), compliance schedule sampling by the City, investigative and permit sampling, and revenue sampling. IU self-monitoring frequency is determined based on the nature of the discharge type, the type of operation performed, the contaminants used, generated, or stored, and the volume of discharged flow.

Routine monitoring by the City consists of the City sampling IUs regulated under Basic or Full discharge permits at a minimum frequency of twice per year for metals (Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn), pH, single toxic organic, and TTO, and at least once each year for cyanide. All CIUs with process wastewater discharges are monitored by the City at least twice per year for all federally regulated contaminants. Additional contaminants may be monitored if present in IU operations.

Violations of discharge standards are resampled in accordance with the requirements contained in 40 CFR 403.12(g)(2). The self-monitoring follow-up sampling is performed by the IU initially and then once demonstrated that the facility has returned to compliance, the RWQCP staff typically performs violation follow-up monitoring to confirm compliance independent of information supplied by the IU. Compliance schedule sampling is conducted when the IU is found to be in significant noncompliance for three successive quarters.

Investigative and routine sampling is performed at any time the inspector needs information on the composition of a waste stream or observes indications of potential noncompliance. The RWQCP staff may take samples during the permitting process to confirm information submitted by the IU and assist in generation of discharge permits.

The City also performs revenue sampling, whereby the city collects samples used to determine the strength of contributing waste streams for recovery of WWTP O&M costs from its partner agencies. Samples are taken once each month. COD, suspended solids, and ammonia samples are used to determine the strength of contributing waste streams. In addition, the following contaminants or contaminant properties are typically monitored for additional surveillance of trunklines at the same time as revenue sampling: Ag, As, Ca, Cd, Cl-, Cr, CN, Cu, Hg, Mg, Na, Ni, Pb, SO_4^{2-}, pH, specific conductance, Se, TDS, and Zn.

The City also inspects IUs regularly with the frequency depending on the type of facility, discharge volume, facility size, and compliance history. Minimum inspection frequencies are summarized in Table 4-11. The following types of inspections are conducted by program staff: pre-permit inspection, violation inspections, routine compliance inspection, special investigation inspections, and sampling inspections.

Table 4-11. Minimum Inspection Frequencies.

Facility Type	Minimum Inspection Frequency
CIU/SIU	Annual
Categorical (Zero Discharge)	Annual
Non-Categorical (SIU)	Annual
Non-Categorical (non-SIU)	Annual
BMP	Annual
Permitted Vehicle Service Facility	Annual
Non-Permitted Vehicle Service Facility	Annual
Photo-Processing	Annual
Groundwater	Once during permit cycle
Machine Shops	Once during permit cycle
Food Service Establishments	Typically once every 3 years
Dental offices that remove or replace amalgam	Typically 20% each year

4.8.8 Outreach Efforts

As part of its NPDES and Municipal Regional Stormwater permits, the City of Palo Alto provides public outreach to increase pollution prevention best practices in residential, business, school, or other communities and educate individuals on how activities can prevent pollution of the Bay.

To work within schools, Palo Alto contracts with a nonprofit organization called Grassroots Ecology to offer programs with elementary and middle schools within East Palo Alto Sanitary District, Los Altos, Mountain View, and Palo Alto. In the 2018-2019 school year, the program delivered 136 school programs, reaching more than 3,000 students. In 2020, Palo Alto had continued outreach efforts, although because of the COVID-19 pandemic, expectations were modified. For the 2019-2020 school year, the program delivered 67 programs directly to classes. A remote-learning dashboard and lessons were viewed by approximately 200 teachers in the service area and the program has provided extensive outreach to teachers as schools transitioned to distance learning.

The 2020 residential and business outreach program consists of:

- Topical inserts within utility bills that cover topics such as pool draining, pest control, and pharmaceutical disposal. Additional digital and print ads on the same topics ran concurrently with utility bill inserts.
- A public outreach website, www.cleanbay.org, provides watershed protection information for residents, businesses, industry, and schools.
- Special events and workshops such as setting up educational booths, a creek walk, and an annual World Water Monitoring Challenge.
- Collaboration with Santa Clara Valley Urban Runoff Pollution Prevention Program and Bay Area Pollution Prevention Group in regional outreach efforts.

4.8.9 Future Implementation Steps for ESCP

Looking to the future for a potable reuse ESCP, the following elements, among others, would be considered for addition to the existing Pretreatment Program.

- Develop a Source Mapping and Rapid Response System
  - Segment the sewer system based on location of industrial dischargers, large sewer mains, and pump stations.
  - Develop a rapid response sampling program that begins at the WWTP and then moves up the collection system through sampling of key nodes.
  - Develop and refine documentation of industrial dischargers with respect to POCs for potable reuse so that ESCP staff know which dischargers may potentially be a source of contamination.
- Staffing
  - The ESCP will require additional staffing time, the level is to be determined.
    - DPR will require a greater level of effort compared to IPR
    - Online monitoring may allow for some reduced staffing efforts
  - The ESCP management and staff would:
    - Collect and log all relevant data from the collection system and the RWQCP.
    - Coordinate and routinely meet with the manager of the RWQCP, AWTP (future), and groundwater monitoring program (future) on data from raw wastewater to advanced treated water.
    - Analyze online data for trends indicating potential upsets in the treatment process.
    - Report any concerns, issues, and violations to Valley Water management. Any finished water violations would be reported by others to the RWQCB.
    - Support or lead industrial audits, collection system sampling, and outreach efforts.
    - Revise SUO and Pretreatment Program oversight to include dischargers previously not of concern for NPDES permit compliance but of concern for potable reuse.
- Sampling and Analytical Testing
  - Initiate an enhanced sampling program that evaluates regulated and unregulated contaminants at the RWQCP effluent, RWQCP influent, and at nodes in the collection system.
  - Establish a tiered monitoring system that increases sampling for contaminants that may pass through treatment and/or are at concentrations with small margins of safety while decreasing sampling for contaminants that do not pass through treatment or are at concentrations with large margins of safety.
  - Evaluate the use of real-time monitoring in the collection system that can support both conventional local limits enforcement as well as provide an early warning system for potable reuse.
- Public Outreach Efforts
  - Integrate language that informs the public of potable reuse into existing programs and outreach efforts.
  - Develop or broaden existing programs to provide information to public and commercial dischargers that includes language that encourages protection of the sewer shed and that keeps potable reuse in mind.

4.9 Case Study Summary

In general, the conversion from a conventional pretreatment or source control program to an ESCP is a substantial effort, depending upon the rigor of the existing program. The participating utilities interviewed for this section were intentionally in different phases of implementation, which results in different perceived or real challenges from project to project. Several overarching themes from these case studies emerged:

- Level of Effort
  - *For small utilities with only limited pretreatment programs*, jumping to an ESCP represents numerous challenges. There will be large impacts to staffing and laboratory expenses (assume annual costs of $200,000) as well as a lengthy period of time to get the program operational (from scratch, could be 2 years).
  - *For medium to large utilities with aggressive pretreatment programs*, the added level of effort is much smaller. Impacts include a larger number of POCs and increased laboratory budgets, the amount of which depends heavily on the size of the collection system and diversity and density of industry.
- Targeted Limits
  - Broad local limits can be applied to all industry, but such an approach will result in overregulating some industries.
  - Targeted limits, based upon a clear understanding of loading and risk of particular contaminants and treatment ability at the WWTP or AWTP is the most efficient way to impose limits on industry. For some of the case studies, limits for a particular contaminant were applied to large dischargers but not small dischargers.
- Monitoring
  - ESCPs require an expansion well beyond industry-led sampling. Grab samples by utility staff is needed to better regulate water quality.
  - Grab sampling only represents a small portion of water quality, with many hours left unmonitored. Online monitoring systems can be used to measure water quality throughout the day and provide valuable information to source control staff as they look to track abnormal or even illegal discharges back to their source.
- Interagency Agreements
  - The breadth of analytes and depth of sampling needed for an ESCP far exceeds the typical pretreatment program efforts. This impacts laboratory costs, staff time, costs for analysis of data, and field staff time auditing industry.
  - Early in the development of potable reuse programs, agreements or memoranda of understanding are needed between the leading water agency that will benefit from the new recycled water and the wastewater utility that has experience and authority over the sewer collection system.
- Industry
  - Constant dialogue with City planning staff is needed to track new businesses in town.
  - Direct and repeated engagement of industry is needed so that they are keenly aware of the need for a project as well as their role in protecting water quality.
  - There is no “ideal” industry, as there is no “typical” bad actor. Industries that discharge challenging contaminants have shown to be good partners on potable reuse projects in

many cases. Conversely, seemingly benign industries have been shown to be challenging partners on potable reuse projects in some cases.

- A robust engagement and monitoring program for industry should begin 12 to 24 months ahead of potable reuse production and carry on through the life of the project.
- A robust enforcement authority, as detailed by a SUO, is mandatory for long-term success.
- In total, a robust and vigilant ESCP is necessary for every program, even those with little to no CIUs or SIUs.

A summary of each individual case study is presented in Table 4-12.

Table 4-12. Summary of Key Case Study Results.

Utility	Plant Upsets	Industrial Dischargers	Monitoring and Enforcement	Outreach	Local Limits Summary	Other Considerations
City of Pismo Beach, California	Annual early summer upsets are seen, but do not result in NPDES compliance. A detailed sampling plan could be initiated to better understand the cause of such events.	Unregulated discharges, such as waste haulers or RV disposal areas present a risk pathway. Developing a manifest/approval system for all dischargers, even those that seem benign, is recommended.	The City currently does not have sufficient enforcement authority in their SUO for the future potable reuse program support.	Outreach and education will need to be expanded ahead of a potable reuse program.	Small pretreatment program focused on oils and grease. Requires enhancements for potable reuse, even though industry in town is limited.	For a small facility, implementation of online monitoring of target parameters at the head of the WWTP provides greater comfort in feed water quality while reducing the level of grab sampling efforts in the collection system.
City of Morro Bay, California	Plant upsets not typically seen.	The City has completed an IWS to evaluate every discharger to the collection system to support the upcoming potable reuse program. Two dischargers were deemed important and are cooperating with the City.	The City has developed a robust SUO to support the potable reuse program along with an ERP and Monitoring Program.	Due to the small size of the community, existing engagement through community events, flyers, and billings is deemed sufficient.	Small pretreatment program focused on oils and grease. Requires enhancements for potable reuse, even though industry in town is limited.	Moving from a FOG program only to an ESCP will be costly for Morro Bay. Estimated costs are $150,000 in annual personnel costs, $60,000 in new monitoring equipment, and annual laboratory costs of $5,000.
City of Santa Cruz, California	Plant upsets not typically seen.	The City has a small number of SIUs and one CIU which are closely monitored, along with 450 permitted industrial dischargers.	With a good SUO, utilities are able to create both broad and specific numeric limits for contaminants that pose a risk to effluent discharge and potable reuse water quality.	Development of SOPs for different industries as well as community clean water events can be used to develop collaborative relationships with industrial dischargers.	Aggressive local limits program with expanded list of contaminants as part of the Ocean Plan. Extensive testing underway to determine if new contaminants must be added to the local limits program to support potable reuse.	Having a robust and required communication process between the business departments of the cities with the wastewater/water departments for the utilities is critical to track new potential dischargers to the collection system.

(Continued)

Table 4-12. Continued.

Utility	Plant Upsets	Industrial Dischargers	Monitoring and Enforcement	Outreach	Local Limits Summary	Other Considerations
City of Altamonte Springs, Florida	Plant upsets not typically seen.	The City has only one SIU, which is also a CIU. This SIU collaborates well with the City. Future potable reuse will require more proactive monitoring of existing and new potential industrial dischargers.	In anticipation of future potable reuse, the City has developed a detailed Source Tracking system, which details the various industries within the collection system, allowing for rapid tracking of future water quality challenges back to the source.	Community outreach is currently limited and needs expansion ahead of the potable reuse program.	Small pretreatment program based on limited industrial dischargers with the collection system. Success of potable reuse demonstration suggests that current program is sufficient to protect water quality but more detailed analysis will be part of future potable reuse program.	
LACSD, California	Plant upsets have been minimized through an aggressive pretreatment program.	With more than 2,500 industrial dischargers, a rigorous system of inspections, reporting, and rapid response is essential to maintaining, tracking, and enforcing wastewater quality.	With a robust ERP, utilities can track contaminants back to the source for subsequent corrective action.	Recognition of good stewards and hosting industry forums contribute to source control success.	Extensive pretreatment program supports current potable reuse program. New local limits and/or practices may be employed as the future JWPCP potable reuse project is initiated.	Authority to have flexible standards for the broad range of industrial dischargers is necessary, instead of a uniform set of local limits for all industrial dischargers. CWT and hauled waste require focused attention.

(Continued)

Table 4-12. Continued.

Utility	Plant Upsets	Industrial Dischargers	Monitoring and Enforcement	Outreach	Local Limits Summary	Other Considerations
HRSD, Virginia	HRSD sees frequent upset events at the NTP where high nutrient and organics entering the plant challenge the downstream AWTP.	HRSD has 175 permitted industries, including 57 SIUs and 19 CIUs.	HRSD has demonstrated success tracking challenging contaminants back to the source and developing winning collaborative strategies with industry to minimize the challenges. Examples include bromide and 1,4-dioxane (from landfill leachate), and acrylamide (chemical manufacturer).	HRSD engages industry two or three years ahead of implementing potable reuse, which allows for a gradual educational process followed by collaborative solutions. Bringing industry to the SRC improves industrial support for the program.	HRSD has site-specific limits for many industries, attempting to minimize the use of broad local limits which may not be appropriate for many dischargers. HRSD focuses on the total load of a contaminant from an industrial discharger, which results in heavy dischargers of a particular contaminant being regulated whereas small dischargers may not.	HRSD identified three types of industries that present the largest challenge to their program: (1) Landfills, (2) Organic Chemical Manufacturers, and (3) Meat and Poultry.
City of Palo Alto, California	Plant upsets not typically seen.	Within the City, and neighboring communities that discharge into collection system, are 123 permitted IUs, with 10 CIUs and two SIUs. These industries present minimal challenges to treatment plant operation.	The City's SUO provides clear enforcement capabilities within the collection system, which could include future discharge limitations related to potable reuse.	The City partners with a nonprofit organization to offer programs to elementary and middle school students focused on pollution prevention best practices. The City has a robust outreach program that provides information to industries and residents through various forms including factsheets, event tabling, utility bill inserts, and web pages.	The City reviews and updates local limits based on changes in treatment, operations, regulations, or the industrial user database. Initiation of a potable reuse program would result in a review and possible update of the local limits program.	

CHAPTER 5

Industrial Enhanced Source Control Program Framework

This section presents a proposed framework to help utilities establish an Industrial ESCP. This proposed framework incorporates the results of Tasks 1 through 3 of this project and integrates ESCP recommendations from other guidance documents, notably the:

- Framework for Direct Potable Reuse (Tchobanoglous et al., 2015)
- Proposed Framework for Regulating Direct Potable Reuse in California: Second Edition (CA SWRCCB 2019) and its addendum (CWB 2021a)
- Guidelines for Source Water Control Options and the Impact of Selected Strategies on Direct Potable Reuse (Rimer and DeCarolis 2017)
- Enhanced Source Control Recommendations for Direct Potable Reuse in California (NWRI 2020)
- Australian Sewage Quality Management Guidelines (WSAA 2012)
- Defining Potential Chemical Peaks and Management Options (Debroux et al. 2021b)

The objectives of the framework are to:

- Develop an ESCP that:
  - is industrially focused
  - accommodates utilities of all sizes
  - accommodates utilities with no formal pretreatment programs as well as those with existing NPPs
  - functional for all potable reuse system types
- Compile and build on previous work that outlines steps for industrial-focused ESCPs
- Build on best practices from utilities with existing ESCPs

This proposed ESCP framework is focused on industrial contributions to the collection system and does not provide guidance for commercial and residential contributions, which also require attention during the formation of an ESCP. Thus, it is referred to in this report as an Industrial ESCP, though it is acknowledged and recommended that the Industrial ESCP be incorporated into the full ESCP prior to the potable reuse system starting operation. The proposed Industrial ESCP framework also does not differentiate between DPR and IPR applications. While there are nuances in how any particular system would apply the framework to their situation, the objective was to create a robust framework that is functional for all potable reuse systems.

The proposed framework includes 13 steps that are separated into four phases based on the approximate timing that each step should occur relative to the potable reuse project. While the recommended timing of each phase may vary depending on the size of the project, the intent was to help identify which tasks need to be completed prior to committing significant resources to the project (Phase 1), tasks that need to be completed prior to design of the advanced treatment facility and other associated infrastructure (Phase 2), and tasks that can be completed during design or construction (Phases 3 and 4). Figure 5-1 presents the four phases of the Industrial ESCP framework and the recommended timing.

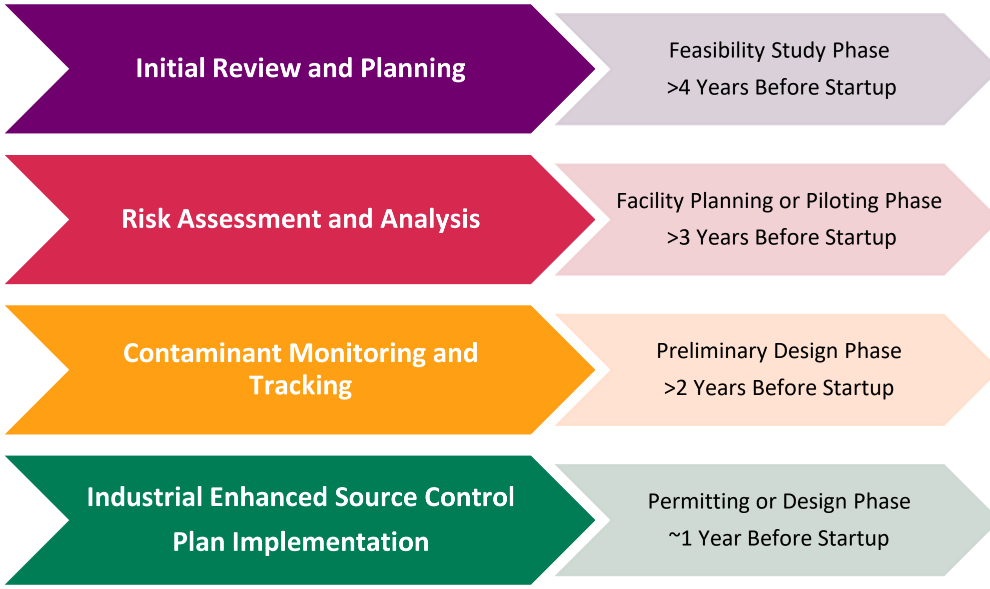

Figure 5-1. Phases of the Industrial Enhanced Source Control Program Framework.

5.1 Phase 1: Initial Review and Planning

Figure 5-2 presents an overview of Phase 1, which includes five steps and is intended to set the foundation for the planning of the Industrial ESCP, and to many extents, the full ESCP. These are all high-level steps that should occur during the feasibility study phase, approximately four or more years prior to project startup for full-scale facilities. These are discussions and decisions that should be initiated prior to committing significant resources to the potable reuse project as these items can significantly affect the resources needed for the Industrial ESCP to be successful. The Phase 1 activities can mostly be performed in parallel but should be completed before Phase 2 is initiated. It is recommended that the utility develop an ESCP feasibility study report that summarizes the results of the steps in Phase 1 prior to proceeding to Phase 2. The following sections provide a more detailed explanation of each step.

INITIAL REVIEW AND PLANNING

1. Review existing National Pretreatment Program authority
2. Identify partner agencies, begin interagency discussions, and consider stakeholder engagement and public outreach plans
3. Review existing industrial pretreatment program
4. Identify Technical, Managerial, and Financial (TMF) Capacity
5. Identify contaminants to monitor and begin WWTP sampling program
   - Regulated drinking water contaminants
   - Industrial contaminants with special concern for potable reuse
   - Contaminants known to be a challenge for the utility
   - Pass-through hazards, interference hazards, and the highest ICSS contaminants for the selected AWT train

Feasibility Study Phase (>4 years before project)

Figure 5-2. Initial Review and Planning.

5.1.1 Step 1. Review Existing National Pretreatment Program Authority

As discussed in Chapter 1, the NPP applies to POTWs with a capacity of 5 mgd or greater or those that receive non-domestic pollutants that have a potential to impact the POTW. For these facilities, the ESCP can be thought of as an extension of the NPP structure and authority that already exists. For facilities without an existing NPP, a similar program will need to be established for the ESCP which could require significant effort and resources. It is important that this is done early in the potable reuse project timeline to avoid surprises or fatal flaws once significant resources have already been applied to the project.

Whether the utility is or is not already regulated under the NPP, it is recommended to identify if the NPP authority is the state or the EPA and to contact the responsible NPP representative to discuss the project. A relationship with this representative will be needed as the ESCP progresses from planning to implementation and the remaining steps of this framework are navigated. If the utility does not already have a NPP, this representative, among others, can still provide an understanding of the steps and resources needed, although the program that is ultimately developed will continue to not be regulated under the NPP. Key topics to discuss are:

- What contaminants or groups of contaminants are prohibited from industrial discharge?
- How are categorical standards applied?
- How are local or site-specific limits implemented and what is the legal authority (i.e., utilizing the NPDES permit requirement as the authority to determine permitted limits)?
- Does the legal authority specifically authorize potable reuse as a beneficial use category where limits can be applied? If not, is there general language that can reasonably be considered to include potable reuse?
- Which contaminants, or groups of contaminants, can have enforceable local or site-specific limits? Are they limited to only contaminants that are in the potable reuse permit? Can both regulated contaminants and unregulated contaminants be included? Do unregulated contaminants need to have a defensible health-based notification limit or advisory limit?
- What level of communication is required as the Industrial ESCP is established, to NPP, to industries, and to the public?

The outcome of this step should be an understanding of how to utilize the existing NPP authority to implement the aspects of the Industrial ESCP that are needed to implement this framework. For utilities that are not currently regulated by the NPP, additional discussions may be needed to understand how the Industrial ESCP will be implemented and enforced. In these cases, the regulatory authority may be state or local agencies, as it was for Morro Bay (Section 4.3).

5.1.2 Step 2. Identify Partner Agencies, Begin Interagency Discussions, and Consider Stakeholder Engagement and Public Outreach Plans

Some potable reuse projects are implemented by a utility that owns and operates both the advanced treatment and wastewater systems. In these cases, implementing an ESCP (note that this step does not differentiate between an ESCP and an Industrial ESCP as it is important for both) means connecting different people or groups under the same organization and requires new meetings and increased communication. It still takes significant effort to plan and implement the ESCP, but the success of the program can be dictated by a single entity. An example of this type of program is provided in the HRSD case study in Section 4.7.

In contrast, many potable reuse projects are implemented by a drinking water utility that will use the wastewater effluent from a different utility. In these cases, an interagency agreement is needed that identifies all the ways that the wastewater utility and drinking water utility will collaborate to make the potable reuse project successful. These agreements cover flows, water quality, and the ESCP, among others, and can be very challenging to find a consensus. While the drinking water utility is often the driver of these discussions, the wastewater utility will bear the responsibility of implementing the ESCP. An agreement is needed for how the wastewater utility will increase resources to support the ESCP, which is often paid for, but not executed, by the drinking water utility. This can be particularly onerous for regional wastewater utilities that do not own or operate parts of its collection system and for utilities that are not regulated under the NPP. An example of this type of collaborative agreement between a water utility and a wastewater utility is discussed in the City of Santa Cruz case study in Section 4.4.

It is important to identify partner agencies and initiate these interagency discussions early in the planning of the potable reuse project. These discussions will occur in the project feasibility phase to discuss flows and water quality, but it is important to also discuss the ESCP at this early stage. The ESCP requirements, beyond the NPP, can be substantial to the wastewater utility, so it is also important to start the ESCP discussions with the following key discussion points:

- The safety of the DPR system depends on a well operated advanced treatment facility, a well operated wastewater facility, and a robust ESCP. A failure or lapse in any of these three can compromise the water quality for the community.
- The industries, businesses, and residences that discharge into the collection system are now stakeholders in the potable water system and additional monitoring and communication is appropriate.
- At its core, an ESCP consists of additional monitoring, a risk assessment, and a pollutant tracking strategy. The goal is not to completely overhaul the existing NPP structure or to

significantly increase the local limits program. In some cases, for robust and detailed NPPs, limited resources are needed to extend the existing NPP to cover the ESCP requirements (see Chapter 4 for examples from City of Santa Cruz and LACSD).

If the potable reuse project has progressed into the feasibility study phase, it is likely the utility is already working on a public outreach strategy. It is important that this strategy include communication about the ESCP and that industries are identified as stakeholders early and included in the outreach. Having an industry-focused public outreach strategy is recommended to establish good relationships and realistic expectations early in the process. The industrial community is often not aware what happens to their discharged wastewater and thus do not understand the risk they pose to the potable reuse system. Notably, hospitals examined did not know the fate of their wastewater and the impact of flushed pharmaceuticals (WRF 2016). The first step is engaging each discharger to discuss the project and any specific concerns that have been identified.

Industrial dischargers are not only a key stakeholder from a water quality point of view, but also are important discharge ratepayers, water customers, and are part of the local community as employers at a minimum. With proper information and outreach, industrial dischargers may understand that it can be in their best interest to cooperate during the ESCP planning phase so that their business and concerns are accurately considered when sampling data, potential hazard screening, and local limits are considered.

Best Practice: Industry engagement is key to successful ESCP implementation. Recommendations include:

- Frequent communication with industries so they keenly understand their role in protecting water quality
- Constant dialogue with City Planning Departments to track new business/industry
- There is no "ideal" industry and no "typical" bad actor; treat each industry independently and respectfully
- An empowered and robust enforcement authority is mandatory for success

5.1.3 Step 3. Review Existing Industrial Pretreatment Program

In this step, the utility examines various aspects of the existing industrial pretreatment program, whether it is regulated by the NPP or not. A thorough review is recommended so the various project stakeholders understand what is currently being performed and how aspects of the Industrial ESCP can be added to existing practices. This step lays the foundation for Industrial ESCP implementation. After this step, the utility should start to get an understanding of the additional resources that will be needed to enact the Industrial ESCP.

The following criteria should be included in the summary of the existing industrial pretreatment program:

- Number and type of permitted industries, specifically including SIUs and CIUs
- Differences in sampling and inspection practices between different industries
- Historical water quality and flow data available for each industry and within the collection system
- Inventory of chemicals used and stored at each industry
- Prohibited discharge contaminants and applicable categorical limits
- Local or site-specific limits that have been applied to different industries
- Industries that have a history of violations, noncompliance, and those with contentious relationships
- Waste hauler program, either at the WWTP or a permitted industry (such as a CWT)
- Challenging industries, such as landfills and metals finishers
- Discharge frequency for intermittent dischargers
- Number of staff dedicated to industrial pretreatment program and their responsibilities
- Laboratory and analytical resources used for existing sampling program
- Known or anticipated future industrial growth areas within the collection system

An understanding of the existing industrial pretreatment program is very helpful in understanding how the Industrial ESCP will be implemented. Reviewing the industrial discharge data can be helpful in identifying which industries might be challenging for the advanced treatment facility. Industries that have existing compliance or water quality challenges may not always be the same industries that will be a challenge for potable reuse as the contaminants that pass through or interfere with wastewater treatment can be quite different from those that pass through or interfere with advanced treatment.

5.1.4 Step 4. Identify Technical, Managerial, and Financial Capacity

In previous studies and guidance documents it was noted that the technical expertise, managerial bandwidth, and financial resources needed to plan, permit, implement, and operate a successful potable reuse project are very important and may be underestimated at the beginning of project planning (WSSA 2012, NWRI 2021). This is particularly true for an ESCP, which is often not considered during the feasibility study phase.

The technical and managerial capacity to lead the ESCP should be evaluated based on the existing pretreatment staff. Larger utilities might consider creating a new position within the pretreatment group that focuses on ESCP. Smaller utilities might increase the existing responsibilities of the pretreatment manager to include the ESCP. In either case, it is important that the ESCP have a manager or point person that has the time to devote to ESCP issues and the technical expertise to understand how the ESCP affects the potable reuse program. It is recommended that the overall ESCP has a point person for all aspects of the ESCP, not just the Industrial ESCP.

While various stakeholders estimate the total capital and operating cost of the potable reuse program, it is important to include the additional cost and resources needed to implement the ESCP (industrial and other components). After Step 3, the utility should have a robust understanding of the existing industrial pretreatment program. An understanding of the rest of this framework can help the utility estimate the additional resources that are needed for sampling, monitoring, analysis, and enforcement. In cases where there are interagency agreements, it is particularly important to estimate additional ESCP resources early in the project phase. Table 5-1 provides a high-level summary of the estimated cost for implementing an ESCP (full ESCP, not just Industrial ESCP) from four of the utilities interviewed in the case studies summarized in Chapter 4.

Table 5-1. Summary of Estimated Costs to Implement an ESCP.

Utility	Total Average WWTP Flow (mgd)	Number of Permitted Industries	Estimated Additional Cost to implement ESCP	Notes
City of Morro Bay	0.8 mgd	0 (not regulated by NPP)	>$215,000 per year	Estimated costs of transitioning from a FOG program only to an ESCP are $150,000 in annual personnel costs, $60,000 in new monitoring equipment, and annual laboratory costs of $5,000.
City of Santa Cruz	6 mgd	450	$100,000 per year	Costs for upgrading NPP to ESCP are focused on analytical costs for new contaminants. Additional monitoring costs are estimated at $75,000/year and require an estimated additional personnel cost of $25,000/year. Pretreatment team consists of 3 FTE and has an annual budget of $880,000/year.
LACSD	390 mgd	2006	$150,000 per year	Robust IW program consists of 65 FTE and has an annual budget around $15 million. The majority of the resources are for baseline industrial pretreatment. Additional costs to support the ESCP include sampling for MCLs and CECs at the influent and effluent of each WWTP and source control investigations for NDMA, PFOA, and other contaminants. No staff were hired specifically to support the ESCP.
HRSD	250 mgd	175	$440,000 per year	Current ESCP (fully implemented for one of HRSD's 7 WWTPs that will be involved in SWIFT) has increased the pretreatment inspection team from 6 FTE to 7 FTE, at a cost of $90,000/year. SWIFT has required significant analytical costs but has not resulted in additional monitoring events. The estimated annual cost at the 1 WWTP where SWIFT is currently implemented is $100,000/year. The total analytical cost for all 7 WWTPs is $350,000/year. The annual budget for HRSD's pretreatment team is around $2.8 million.

5.1.5 Step 5. Identify Contaminants to Monitor and Begin WWTP Sampling Program

A critical step is the identification of the contaminants that will be monitored in the potable reuse project as a whole and the initiation of a sampling program at the WWTP. The list of contaminants to monitor is challenging to develop as it is comprehensive and should include a list of regulated water quality parameters and additional contaminants that are relevant for potable reuse projects. This step provides a recommendation for the types of contaminants that should be monitored to support the Industrial ESCP, though additional recommendations are noted for contaminants that should be sampled for the full potable reuse program and may be part of the full ESCP.

Once the list of contaminants is identified, the frequency and locations of sampling can be determined and a full sampling plan can be generated that can help inform the resources needed for the sampling program. Most of the contaminants needed for the Industrial ESCP will also be needed to determine the advanced treatment train and design criteria. The goal is to generate this list early so that sampling can produce a meaningful data set prior to the advanced treatment facility design. If sampling identifies a higher concentration than expected of a particular contaminant, the design team can then determine what treatment steps are needed to address that contaminant. Note that sampling prior to design allows for treatment to be designed to address challenging contaminants, as opposed to identifying the challenging contaminants after design is complete and having to rely on source control.

Developing a sampling plan can be a daunting process because of the number of contaminants that exist and are potentially of concern to health regulators and the community. It is recommended that the contaminants be broken down into four groupings as shown below. Once the list of contaminants is developed, the WWTP sampling program should start. It is recommended that this process of identifying contaminants is repeated at a regular frequency (every 5 or so years) or whenever significant changes occur in the collection system.

5.1.5.1 Group 1: Regulated Drinking Water Contaminants

The first group are the regulated contaminants for the potable reuse project. This likely includes the EPA primary MCLs, secondary MCLs, and state MCLs or NLs, if applicable. Note, the pathogens (e.g., enteric viruses, Giardia, Cryptosporidium) and pathogen indicators (e.g., E. Coli, total coliform) are likely included in the list of regulated water quality criteria, although these are not relevant for the Industrial ESCP. This list may also include TOC, TN, TP, TDS, or other criteria as determined by the regulations. It is important to work with the relevant regulatory agencies early in the process to identify the advanced treated water requirements and have a clear list of all contaminant levels that must be met.

5.1.5.2 Group 2: Industrial Contaminants with Special Concern for Potable Reuse

This group of contaminants includes health-based indicators that are monitored or recommended for monitoring in potable reuse projects but are not yet regulated. These contaminants are often, but not always, present in wastewater effluent and are of concern in potable reuse projects because of their potential health impacts, indication that other contaminants might be present with potential health impacts, and potential for interfering with advanced treatment. Example contaminants include:

- 1,4-dioxane
- Nitrosamines (NDMA and NMOR at a minimum)
- PFAS (those that have local, state, or federal regulatory relevance, and those that have published toxicological metrics)
- Formaldehyde, acetone, and other relevant low molecular weight compounds
- Bromide and other industrial contaminants with potential for DBP formation
- Iron, manganese, hardness and other contaminants with potential for interference with advanced treatment (see Section 2.7)

It may not be necessary that every utility monitor for every parameter listed above, but these are the types of contaminants that should be discussed when developing the sampling plan. These contaminants have been frequently monitored and researched in past potable reuse projects and can be helpful in confirming the viability of the treatment process and communicating the safety of the project to the public.

There are many emerging contaminants that are relevant for potable reuse projects. It is likely not feasible for every utility to sample for every emerging contaminant, but it is important for each utility to identify which contaminants are relevant for their specific project. It is recommended to evaluate local, state, and federal regulations and guidelines and to track discussions that are occurring at each of these levels. Contaminants that are being considered for regulations or limits are good candidates to include in a sampling program. This is most pertinent for PFAS as many advancements are expected in the next several years and utilities implementing potable reuse projects should be sampling for contaminants so that they understand the impact of any proposed limits.

The wider sampling list for the full potable reuse program likely includes additional parameters that are regulated contaminants, such as pathogens or pathogen indicators, and unregulated performance indicators that do not have known health impacts, such as sucralose. These classes of contaminants are important for the project but are not relevant for the Industrial ESCP as they do not have significant industrial sources.

5.1.5.3 Group 3: Contaminants Known to be a Challenge for the Utility

This group of contaminants is entirely specific to each utility and to the contributors to the collection system. The existing pretreatment team should first brainstorm the existing challenges to the collection system:

- What contaminants come into the WWTP and cause problems?
- What are common contaminants that are reported for industrial violations?
- Which industries are especially problematic and what contaminants are typically discharged?
- Are there chemical manufacturers and, if so, is there a list of chemicals that are used in the manufacturing process?

The goal of this group is to identify contaminants that are not regulated and are not the common potable reuse contaminants but might have risk to a specific collection system. Another goal of this group is to start to identify and focus on the more challenging industries, the ones that pose the biggest risk to the potable reuse project.

5.1.5.4 Group 4: Pass-Through Hazards, Interference Hazards, and the Highest ICSS Contaminants for the Selected AWTP Train

Chapter 2 included a literature review that identified the contaminants that are most at risk of pass-through or interference for potable reuse systems. Table 2-19 lists the pass-through and interference hazards for Trains A, B, and C. It is recommended that the utility include all pass-through and interference hazards in the sampling plan for the selected AWTP train. This will help the AWTP design both by selecting appropriate technologies and design criteria to mitigate the pass-through risks and by adding elements to the design to address the interference hazards.

In addition to the pass-through and interference hazards, it is recommended that the highest ranked ICSS contaminants be included in the sampling plan. Section 2.5 discusses the development of ICSSs, which evaluates the toxicity and anticipated removal through advanced treatment for a long list of contaminants. ICSSs are presented for each of the three trains evaluated. It is acknowledged that the understanding of industrial contaminants is continually evolving and new toxicity and removal values will be constantly available. Utilities are encouraged to use site-specific removal values (from pilot testing) and up-to-date toxicity values when initiating this review.

It is recommended that the utility select the treatment train (Train A, B, or C) that most resembles their project and include at least the top 20 ICSS contaminants in the sampling plan (Table 5-2 shows the top 20 ICSS contaminants for each train, which is copied from Tables 2-6, 2-7, and 2-8; the full list for each train is shown in Appendix A). While the inclusion of only 20 contaminants can seem arbitrary, it is meant to capture the contaminants that have the highest risk potential but not to impose an undue burden on the utility. If additional resources are available, inclusion of more than just the top 20 contaminants should be considered.

It should be noted that a contaminant with a high ICSS may not necessarily mean it is a high risk for the system; the risk of each contaminant is determined once the background WWTP concentration is known (see Section 5.2 for more information on risk assessment). It should also be noted that Chapter 2 provided a list of contaminants with higher ICSS values due to a lack of information available on removal through advanced treatment processes (Tables 2-15 through 2-17). These contaminants are recommended for future treatment research; it is not necessarily recommended that the utilities include all of these contaminants in the sampling plan, but if additional resources are available these contaminants should be considered.

Table 5-2. Top 20 ICSS scores for Trains A, B, and C.
(copied from Tables 2-6 through 2-8)

No.	Train A	Train B	Train C
1	NDMA	NDMA	NDMA
2	PFOA	PFOA	PFOA
3	PFOS	NMOR	PFOS
4	NMOR	PFOS	NMOR
5	1,4-Dioxane	Cobalt	Cobalt
6	Cobalt	PFBS	PFBS
7	PFBS	PFBA	Uranium
8	Uranium	Mercury	PFBA
9	PFBA	Arsenic	Mercury
10	Mercury	Chromium	Arsenic
11	Arsenic	Uranium	Chromium
12	Chromium	Cadmium	1,4-Dioxane
13	Cyanide	1,4-Dioxane	Cadmium
14	2,4,6-Trichlorophenol	Nickel	TCEP
15	1,2,4-Trichlorobenzene	TCEP	TDCPP
16	Atrazine	Selenium	Nickel
17	Cadmium	Fluoride	Atrazine
18	TCEP	Iodide	Carbon tetrachloride
19	1,2-Dichloroethane	Copper	Selenium
20	TDCPP	Carbon tetrachloride	Fluoride

5.1.5.5 Begin WWTP Sampling to Assess Contaminants of Concern

When the list of contaminants to monitor has been identified, the actual sampling program can begin. The sampling program is intended to identify contaminants that pose the highest risk. This can be thought of as a similar process to a source water monitoring program for a conventional WTP; the source water must be characterized before a treatment system can be designed to meet the finished water quality goals. This research project will not recommend sampling frequencies and durations as those should be specific for each project and developed in concert with local regulatory authorities. With that said, the background sampling program should:

- Include enough samples to adequately characterize the system (i.e., quarterly samples for two years or monthly samples for 1 year). A minimum of 1 year of sampling is recommended to understand seasonal variability. A minimum of eight data points is recommended to provide a reasonable data set.
- Focus on sampling of treated wastewater at the same location where water will be diverted to the advanced treatment facility. If this is upstream of the wastewater disinfection step, which is commonly selected to avoid disinfection byproduct formation prior to advanced treatment, it is important that the sampling program also be at this location. Additional sampling of raw wastewater or effluent prior to a filtration or disinfection step can be performed if resources are available. This can provide input on treatment performance of the WWTP or identify byproducts of the WWTP process (i.e., increased acrylamide due to

polymer addition, disinfection byproducts formed by chlorination). Note that the ICSS calculations are based on concentrations in the raw wastewater. Section 5.2.2 discusses how to adjust the ICSS calculation based on the sampling location. Equations 2-1 through 2-5 show how to update the ICSS based on percent removal values that are provided in Appendix A.

- Includes off-ramps for sampling. Some contaminants may require ongoing monitoring as part of the regulatory permits. But other contaminants that are frequently below the detection limit or at a low concentration that does not pose a risk can be reduced or eliminated and then revisited at a later date. There are resources available that recommend how to identify when to reduce sampling and to later revisit contaminants (Drewes et al. 2018). As an example, a contaminant that is originally sampled monthly could be reduced to quarterly, and then to annually, if it is consistently below a threshold and then revisited every 5 years to confirm that concentrations have not increased.
- Review the list of contaminants that are being monitored every three to five years. There are new chemicals identified, and new toxicological information available on different chemicals, every year, and staying informed on research and guidelines is essential to the potable reuse program.

These general recommendations can be used to develop the cost and resources required to achieve the sampling plan. It is important that staff and laboratory resources are available to make the sampling plan successful.

5.2 Phase 2: Risk Assessment and Analysis

Figure 5-3 presents an overview of Phase 2, which includes steps 6 through 8 of the framework and is intended to identify and quantify potential industrial contaminant risk to the potable reuse system, both from chemical spills and from background concentrations. As such, it is important that these steps be completed prior to the start of design of the advanced treatment facility. A document summarizing the contaminant risks and mitigation strategies should be developed at the end of Phase 2.

Risk Assessment and Analysis

6. Identify industrial risks
   - Create a chemical inventory for all industries and list existing control measures
   - Perform site-specific sampling at industries that are known to be a challenge
7. Perform risk analysis using the ICSS framework and measured contaminant concentrations
8. Evaluate, document, and mitigate system risk

Facility Planning Phase (>3 years before project)

Figure 5-3. Risk Assessment and Analysis.

The US EPA uses public health impact data for risk assessment in a similar way to what is proposed in portions of this study. The database that stores the latest health risk data is known as the Integrated Risk Information System (IRIS).

While many people are familiar with the database, the IRIS program also includes guidelines on how to evaluate human health hazards associated with new chemicals and/or new health risk data including for developing drinking water regulations in the context of other considerations.

This phase proposes to use a similar iterative risk assessment model (see Figure 5-4; adapted from NWRI 2020) for assessing risks associated with potable reuse. Risk assessment may be especially iterative for DPR because it is a relatively new frontier and both new contaminants and treatment technologies may alter the risk assessment as the future unfolds. This cycle will continue through Phases 2, 3 and 4.

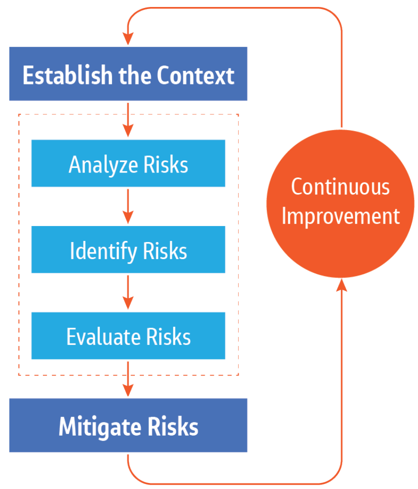

Figure 5-4. Iterative Risk Assessment.

5.2.1 Step 6. Identify Industrial Risks

The goal of this step is to identify the major industrial risks to the system. This includes two major tasks, as described below.

5.2.1.1 Create a Chemical Inventory for All Industries and List Existing Control Measures

When analyzing industrial contaminant risk to potable reuse systems, the focus is typically on a large chemical spill or discharge, intentional or unintentional, that provides a slug dose into the system. The goal of this sub-step is to quantify these types of risks so that they can be mitigated through the Industrial ESCP and through design and operational measures at the WWTP and AWTP.

At this early phase of the project, it is recommended to create a list of all SIUs and identify all chemicals located onsite, the quantities of those chemicals, and any chemicals that are produced as part of the industrial process. Any control measures in place to mitigate and/or detect a spill should also be noted. A site interview may be needed with each SIU to determine this information if it has not already been collected. This information is often collected in existing pretreatment programs as noted in Figure 3-24, which shows 63 percent of utilities maintain a chemical inventory of all permitted industries. If any chemicals are identified in this process that are stored or produced at significant quantities and can present a potential risk, the chemicals should be added to the sampling program that was developed in Step 5.

Once each industry has been reviewed, they should be ranked by the volume of chemical that could potentially be spilled into the collection system, the toxicity of the chemical, and the control measures in place to prevent a spill. This may be an informal or relative ranking process, but it is important to identify the industries that pose the greatest risk and have awareness of the potential impact of a spill.

5.2.1.2 Perform Site-Specific Sampling at the Industries that are Known to be a Challenge

Some utilities have industries in their collection systems that are known challenges, whether inherently because of the type of industry or because of how it is operated or managed. It is prudent for the utility to do some sampling events (up to three events per industry) at these challenging industries during this phase of the project to characterize the discharge. The same contaminants identified in Step 5 should be sampled at each of these industries. It is recommended that all landfills, CWT facilities, and metals finishers be included in this early sampling step as well as any chemical manufacturers that have complex or challenging discharge. If the sampling program at the WWTP starts to identify potential challenge contaminants, this small sampling program might provide insight on where the contaminants are entering the system.

5.2.2 Step 7. Perform Risk Analysis Using the ICSS Framework and Measured Contaminant Concentrations

As discussed earlier and detailed in Chapter 2, this research project identified an ICSS for a wide range of contaminants based on their toxicity and their potential to pass through advanced treatment processes. The following steps detail how to apply the ICSS values and identify the actual risk of different contaminants:

1. Review the data available from regular WWTP sampling (Section 5.1.5). Do not begin this process until at least four sampling events have been performed.
2. Identify the applicable ICSS values. Step 5 of this framework recommended at least the top 20 ICSS contaminants for the selected potable reuse train should be included in the sampling plan. In addition to those 20 contaminants, many additional contaminants in the sampling plan (regulated contaminants, contaminants relevant for potable reuse, pass-through and interference hazards, etc.) will have ICSS values. Review the full list of ICSS values in Appendix A and identify all the contaminants that have sampling data available.
3. Review the pilot data, bench testing data, or other relevant data available on the site-specific removal of different contaminants. The ICSS values are based on conservative estimates from a wide literature review. Where available, site-specific data should be used. For example, Table 2-6 shows PFOA and PFOS with removal percentages of 95% and 97%, respectively, through the Train A process. Literature suggests that RO provides consistent removal of PFOA and PFOS to below detection limit levels. However, to be conservative, the screening process used to calculate ICSS values assigns a maximum value of 95% removal per treatment process. If pilot data shows 99% or more removal for these contaminants, the values in the ICSS tables should be replaced with the updated value. A higher percent removal for a treatment train will reduce the ICSS which will result in a lower overall risk

value for the contaminant. The ICSS calculations include the estimated removal of each contaminant through the WWTP process. However, many potable reuse sampling programs are downstream of secondary treatment at the location where wastewater will be diverted to the AWTP. If this is the case, the estimated removal from the WWTP should be removed from the ICSS calculations. Inclusion of WWTP removal in the ICSS is important as a screening tool, but when applying the ICSS to calculate the risk, the WWTP removal needs to be removed if the sampling is downstream of secondary treatment.

4. The above three steps will provide a curated list of ICSS values based on site specific removal data for the contaminants that are being sampled. As illustrated in the Figure 5-5 flowchart, this step converts the ICSS value into an Industrial Contaminant Risk Quotient (ICRQ) based on the measured WWTP values. Two examples are provided in Table 5-3 to show the math used to calculate the ICRQ. Contaminants with an ICRQ greater than 1.0 merit focused attention to identify potential sources and consider ways to eliminate the source or improve treatment. Contaminants with an ICRQ greater than 0.2 should be tracked in the Industrial ESCP, as recommended in Drewes et al. (2018).

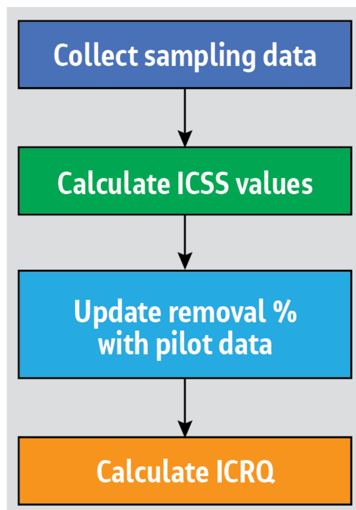

Figure 5-5. Step 7 Flowchart to Calculate ICRQs.

Table 5-3 provides two examples of calculated ICRQs calculated from assumed concentrations of 1,4-dioxane and PFOS detected in a secondary or tertiary treated effluent. The equation to calculate the ICRQ is as follows:

$$ICRQ = C\ in \frac{mg}{L} * \frac{2\ L}{day} * \frac{adult}{70\ kg} * \frac{1}{20\%} * IC\ Screening\ Score\ in \frac{kg * day}{mg}$$

Equation 5-1

In Equation 5-1, ICRQ is unitless, C is the concentration of the contaminant in the wastewater effluent in mg/L, 20% is the default Relative Source Contribution (RSC), and the ICSS is the Industrial Contaminant Screening Score in kg*days per mg. The ICSS is introduced and presented in detail in Chapter 2 and ICSS values are listed in Appendix A. The RSC accounts for the exposure of the contaminant via drinking water relative to other pathways (inhalation, food, etc.). 20% was used as a conservative default value for this analysis as other guidance also uses a default value of 20% (CWB 2018, USEPA 2018). However, a more detailed risk analysis could evaluate specific RSC values for different contaminants.

Table 5-3. Two Example ICRQs.

Parameter	Example 1	Example 2
Contaminant	1,4-dioxane	PFOS
Treatment Train	A (RO-based)	B (GAC-based)
WWTP Influent Sample Concentration[a]	2.0 µg/L	0.05 µg/L
Assumptions to calculate EPA HALs[b]	Avg. consumption: 2 L/day; Avg. wt. per adult: 70 kg; RSC Correction factor: 20%	
Adult Dose Correlation (ADC)	[0.002 mg/L *2 L/day / 70 kg/adult / 20%] = 0.000286 mg/kg/day	[0.00005 mg/L *2 L/day / 70 kg/adult / 20%] = 0.000007 mg/kg/day
ICSS[c]	113 days * kg / mg	7500 days * kg / mg
IC Risk Quotient = (ADC*ICSS)	0.03	0.05
Value in WWTP Influent to Trigger Ongoing WWTP Source Monitoring (ICRQ >0.2)	6.2 µg/L	0.093 µg/L
Value in WWTP Influent to Trigger Source ID & Risk Reduction (ICRQ >1.0)	62 µg/L	0.93 µg/L

[a] For reference, California drinking water NL are 1.0 µg/L for 1,4-dioxane and 0.0065 µg/L for PFOS. The USEPA lifetime HA levels are 200 µg/L for 1,4-dioxane and 0.070 µg/L for PFOS.
[b] Assumes typical EPA lifetime HA assumptions: an average adult weighs 70 kg, consume 2 liters of water per day, 20% of a person's intake of this chemical comes from water.
[c] A higher rejection % for a treatment train will reduce the ICSS, such that the ICRQ would be reduced for a given sample concentration.
Note: HA = health advisories

Note that the ICRQ is calculated using the ICSS and an adult dose correlation in a similar method as an EPA Health Advisory, which incorporates a Drinking Water Specific Risk Level Concentration for cancer (10^{-4} Cancer Risk) and noncancer adverse health effects (USEPA 2018). The assumptions used in this type of calculation assume an average adult weighing 70 kg drinking 2 liters of water per day, and the default RSC of 20%, as described above. These IRIS type health risk assessment calculations do not incorporate a value for days per year or years per lifetime because this consideration is already included in the ICSS value and thus varies from other types of EPA health risk assessment calculations, which assume 350 days per year and a specified number of years as an exposure period. The ICSS values can be used for different types of risk assessments for specific segments of the population by adjusting these factors.

5.2.3 Step 8. Evaluate, Document, and Mitigate System Risk

Steps 6 and 7 of this framework both result in risk assessments. Step 6 identifies industries with quantities of chemicals that can pose a risk to the system if there is a spill or illicit discharge. Step 7 uses background WWTP sampling data from Step 5 and the ICSS values to identify which contaminants will be a challenge for the advanced treatment system. The purpose of Step 8 is to evaluate the system's ability to mitigate the identified risks and document the overall risk of each contaminant.

There are many elements of the potable reuse system that should be examined for the ability to reduce the risk of industrial contaminants. The following steps should be performed:

- Review the advanced treatment train and key design criteria in consideration of the identified risks. Should any treatment processes be added or adjusted to mitigate the identified risks?
- Are any of the pass-through or interference hazard contaminants present in the wastewater at concerning concentrations? If so, does the AWT design need to be adjusted?
- Review the size of the collection system and the environmental (in IPR cases) or engineered (in DPR cases) storage buffer and its ability to attenuate chemical peaks. It is helpful to review the risk of chemical spills within the context of the system's attenuation capacity. Figure 5-6 (Debroux et al. 2021b; adapted with consent of WRF and authors) highlights the impact of storage volumes, time, and dilution in assessing the risks of chemical spills.
- For each risk identified, assess and quantify the time available to identify an off-spec event and divert AWTP water.
- Identify any critical control points that should be added to the WWTP or AWTP that can either directly mitigate risk or use a surrogate to indicate an illicit discharge or system upset.
- Recommend online monitoring or sampling at strategic locations of the collection system or at specific industries to improve response time in the event of an off-spec event.
- Summarize the overall risk and the risk mitigation plan for each risk identified in Steps 6 and 7.
- Identify key recommendations for the WWTP or AWTP that should be incorporated by the design teams.

Example: Steps 6 and 7 identify that background 1,4-dioxane concentrations present a risk and there is an industry that has onsite chemicals with high concentrations of 1,4-dioxane. The utility should:

- Review the AWTP train and piloting data. Does a process need to be added or upgraded to improve 1,4-dioxane removal?
- Identify if any control, communication, or monitoring mechanisms can be implemented at the industry to alert the WWTP and AWTP in the case of a spill.

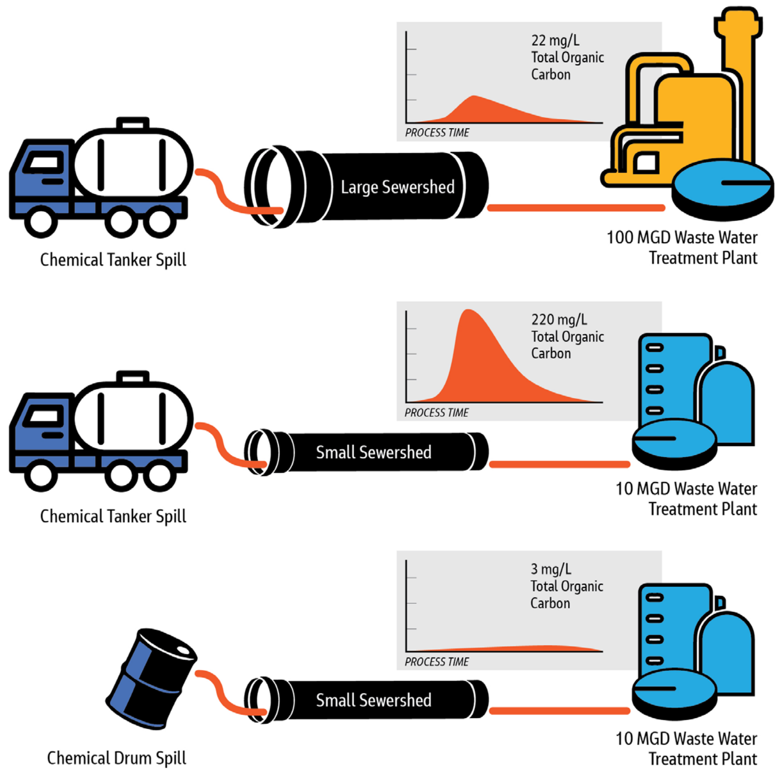

Figure 5-6. Impact of Spill Size, Sewershed Size, and Location for a Theoretical Chemical Discharge.
Source: Adapted with consent from Debroux et al. 2021a.

The above list identifies contaminant risks and potential mitigation strategies. Once these have been identified, it is important to document the risks and mitigation strategies. It is recommended that this be documented in a report that summarizes the identified risks and can be used as a reference once the potable reuse system is operational. If the utility wants to perform a more detailed risk assessment, there are different frameworks and tools used within the water and wastewater industries to assess, rank, and mitigate different types of risks. Detailing out the recommended ways to perform the risk assessment is outside of the scope of this project, but the primary goals of risk analyses are generally as follows:

1. Establish context
2. Identify and analyze known and potential risks
3. Evaluate risks using qualitative and quantitative measures to rank the risk in terms of likelihood, severity of potential consequences, and site-specific considerations
4. Develop risk mitigation plan with strategies to eliminate, reduce or address the risks.

Examples of risk assessment frameworks that have been used for potable reuse projects include:

1. Failure Modes and Effects Analysis (FMEA)
2. Hazard Analysis and Critical Control Point
3. Hazard and Operability Study
4. Event Tree Analysis (ETA)
5. Fault Tree Analysis

Example Best Practice from WSAA 2012 Sewage Quality Management Guidelines 12 Step Risk Management Framework

1. Commitment to Sewage Quality Management
2. Assessment of the Hazards
3. Risk Assessment and Control
4. Operational Monitoring and Control Points
5. Verification and Monitoring
6. Management of Incidences and Emergencies
7. Employee Awareness and Training
8. Stakeholder Management
9. Research and Development
10. Documentation and Reporting
11. Evaluation and Audit
12. Review and Continual Improvement

5.3 Phase 3: Contaminant Monitoring and Tracking

Phase 3 of the Industrial ESCP framework includes Steps 9-11 and is intended to monitor contaminants in the collection system and identify source tracking plans. Phase 3 is recommended to be performed in parallel with design as there should not be any new information in Phase 3 that would significantly affect the design of the AWTP. Step 11 includes submitting the Industrial ESCP (as part of the larger ESCP) for permitting approval, if required by a regulatory agency, which should also occur in parallel with design. Figure 5-7 lists the steps included in Phase 3.

CONTAMINANT MONITORING AND TRACKING

9. Perform industry sampling to identify sources of contaminants
   - Calculate load-based contributions of contaminants by discharger
   - Establish site-specific and local limits, as needed
   - Consider isolating or eliminating specific industrial dischargers
   - Draft pollutant tracking strategy
10. Develop robust sampling and monitoring plan
11. Finalize Industrial ESCP for permitting and implementation
    - Revisit TMF Goals based on identified risks and additional sampling and monitoring requirements

Preliminary Design Phase (>2 years before project)

Figure 5-7. Contaminant Monitoring and Tracking.

5.3.1 Step 9. Perform Industry Sampling to Identify Sources of Contaminants

Now that a risk analysis has been performed, it is time to design and implement a strategy to identify the sources of the contaminants of concern and take action to mitigate the identified risks. This step of the framework focuses on characterizing industrial discharge and prioritizing actions.

Step 6 recommended up to three sampling events at each permitted industry that is known or anticipated to be a challenge for potable reuse. At this phase of the project, it is recommended to perform three sampling events for all SIUs at a minimum (the utility may elect to sample at other permitted or non-permitted industries as needed). The sampling should include all contaminants identified in Step 5 that are still part of the WWTP monitoring program (if sampling has been reduced for specific contaminants due to low concentrations at the WWTP they do not need to be included in industry sampling). This will provide three data points for the permitted industries and at least eight data points at the WWTP. This quantity of data is recommended to perform the source tracking activities described below.

Best Practices for industry sampling:

- Utility sampling is needed in addition to industrial self-monitoring (Section 3.3.5)
- Composite sampling is preferred over grab sampling
- Adding unannounced sampling may not be valuable as it does not always result in different data than announced sampling (Section 4.7.6)
- Online monitoring can be used in the collection system or at industrial discharge

5.3.1.1 Calculate Load-Based Contributions of Contaminants by Industrial Discharger

After collecting three data points at all SIUs, the contribution of each industry to the WWTP can be calculated. A spreadsheet template is recommended similar to the example shown in Tables 5-4. This uses the WWTP data and average flows to calculate the average influent load of each contaminant. This should be performed for all identified contaminants of concern. A separate table (example also provided in Table 5-5) calculates the contaminant load of each industry. Then the theoretical percent load contribution of each industry can be calculated by comparing the industrial load to the WWTP load. If a challenging industrial contaminant has been identified and SIU sampling has not accounted for a significant load percentage, it is recommended to sample at all CIUs that are not SIUs and at any additional industries that might be a significant contributor.

Best Practice: This is a key period for stakeholder engagement, particularly with industries. Challenging contaminants should be communicated to industries so that collaborative solutions can be identified. ESCP messaging should also be incorporated into the broader public outreach strategy during this phase of the project.

It is worth noting that there are many variables in this calculation, including variable/diurnal WWTP flow, variable WWTP concentrations, and variable industrial flow and concentration. However, this is still a useful exercise to screen out which industries are likely to be the significant contributors of each contaminant of concern. It is recommended to maintain these tables indefinitely as more data becomes available and to track any industry with a 5 percent or greater load contribution.

Table 5-4. Example of Load-Based Concentration Template for Challenging Contaminants.

Contaminant of Concern	WWTP Flow (mgd)	Average WWTP Concentration (µg/L)	Average WWTP Load (lb/day)
1,4-Dioxane	10	0.9	7.50×10-2
PFOS	10	0.02	1.67×10-3
PFOA	10	0.04	3.33×10-3

Table 5-5. Example of Load-Based Concentration Template for Industrial Dischargers.

		1,4-Dioxane			PFOS		
Industry	Average Discharge Flow (gpd)	Average Concentration (µg/L)	Average Load (lb/day)	Percent Contribution to WWTP	Average Concentration (µg/L)	Average Load (lb/day)	Industrial User Contribution to WWTP (%)
A	75,000	16	9.99×10-3	13.3%	23	1.44×10-2	19.2%
B	150,000	28	3.50×10-2	46.7%	6	7.50×10-3	10.0%
C	1,000	88	7.33×10-4	0.98%	19	1.58×10-4	0.21%

5.3.1.2 Establish Site-Specific and Local Limits, as Needed.

Once load-based calculations are performed for each contaminant of concern, an action plan can be implemented specific to each contaminant. It is important to note that action plans and the implementation of limits are only necessary if the contaminant risk, either based on WWTP background sampling, industry sampling, or industry risk assessment, exceeds the mitigation capacity of the system. The goal of potable reuse systems should be to only enact site-specific or local limits when treatment of the contaminant at the AWTP would require an excessive capital or operational cost. And of course, limits can only be applied if the utility has already established the legal authority to do so, as discussed in previous sections.

For example, if the 1,4-dioxane influent concentration is high based on WWTP sampling but piloting data suggests the concentration in the advanced treated water will be comfortably below the water quality target, a site-specific or local limit is not needed, even if there is a significant load-based discharger. If the concentration in the advanced treated water is close to the water quality target, limits should be considered. As 1,4-dioxane is an unregulated contaminant by the EPA, the utility would need to determine what state or national limit will be used as the basis for the local limit and check that they have the regulatory authority to do so.

Best Practice for setting site-specific limits:

1. Confirm the legal authority to implement local limits and the contaminants eligible for enforcement
2. Identify dischargers that contribute >5% on a load basis
3. Identify the acceptable load into the WWTP
4. Calculate the portion of the contaminant load that is not contributed by the identified discharger(s). This is the influent background load.
5. Subtract the influent background load from the acceptable load. This is the available load from the identified discharger(s).
6. Divide the available load up between the identified discharger(s) and establish the limits.

Site-specific limits should be pursued in cases where there are load-based contributors of 5 percent or greater. The utility should work directly with the industry(ies) to identify the source of the contaminant, brainstorm alternative chemicals that could be used in the industrial process, and determine if onsite treatment is an option. If a limit is pursued, the utility should calculate what the limit should be for the industry(ies) to have an influent load to the WWTP that will allow the advanced treated water to be comfortably below the water quality target. This process creates data driven, site-specific limits that are defensible. This process also avoids setting limits for industries that do not have a significant load-based concentration of the contaminant.

In many cases, however, there are contaminants of concern that do not have a major industrial discharger or that still have too much influent load even after some dischargers have been addressed. In these cases, local limits may be necessary to reduce the concentrations across all industrial dischargers, but this approach should only be used when major dischargers cannot be identified.

5.3.1.3 Consider Isolating or Eliminating Specific Industrial Dischargers

There may be cases where industry sampling identifies that a particular industry has a significant load-based contribution of several contaminants of concern and it will be very difficult for the industry to treat the contaminants. This is often the case with landfills where there is no reasonable treatment option, and the leachate contains high concentrations of many challenging contaminants and recalcitrant organics. If a single industry is the cause of significant contaminant risk or is requiring the AWTP to add treatment to address contaminants, it is worth considering isolating or eliminating the industry from the collection system. This would hopefully have been identified during Step 6 when sampling was performed at industries known to be a challenge, which would allow the decision to be made prior to AWTP design. But if a contaminant is identified after design, or if regulations change and require a lower limit than the existing design can produce, isolating or eliminating the discharge should be considered.

Alternatively, many utilities have multiple WWTPs in its collection system and can pump the discharge from the challenging industry to a different WWTP. If the decision is made to isolate or eliminate the industrial discharge based on sampling data, it is recommended to work with the industry to attempt to find a collaborative solution before resorting to this step. However, this may be the most reasonable action when considering the additional cost or risk that the challenging industry adds to the system. The utility is recommended to collaboratively work with the industry to identify the best strategy and how to share the cost of the selected path forward.

Some industries discharge contaminants with significant variability and can make it difficult to characterize. Chemical manufacturers can be set up to produce different chemicals at different times of the year which results in different discharge concentrations. CWT facilities can have significant variability based on what type of waste load is being discharged. For industries with known variability, additional sampling and communication is recommended to have confidence that there will be a consistent discharge quality. For chemical manufacturers, a protocol can be identified whereby a sampling event is required for each different manufactured chemical. For CWTs, a set list of samples required for each waste hauler can be implemented. If the utility lacks confidence in the communication or integrity of the industry, isolating or eliminating its discharge should be considered.

If a specific industrial user is a significant discharger of a challenge contaminant, it might be more cost effective to treat for the contaminant at the discharge, prior to entering the collection system. This could offset additional treatment processes or increased chemical doses to treat the chemical once it has arrived at the WWTP and AWTP. Section 4.7.2 provides an example of how 1,4-dioxane was treated at a landfill prior to discharge into the collection system which prevented the need to include UVAOP in the AWTP design.

Task 3 of this project reinforced that there are no ideal industries and no constant offenders. However, there are industry categories that are known to be more problematic for potable reuse systems, such as landfills, CWTs, chemical manufacturers, and metals finishers (see Figure 3-17). If these industries are part of a potable reuse collection system, they require extra attention.

5.3.1.4 Draft Pollutant Tracking Strategy

Each contaminant of concern will have a load-based calculation for each industry and should also have a pollutant tracking and monitoring strategy. If the AWTP is in operation and an analytical sample shows the contaminant concentration is above the acceptable level, the utility will draw on the pollutant tracking strategy to identify potential sources. A pollutant tracking strategy should include:

- Additional WWTP and AWTP sampling to confirm the validity of the initial sample.
- Immediate grab and/or composite sampling at industries with a meaningful load contribution of the contaminant.
- Implementation of online monitoring at the WWTP, within the collection system, or at the discharge of specific industries to identify potential sources of the contaminant. While online analyzers may not be available for the direct measurement of the contaminant, a surrogate may be able to be used to demonstrate a deviation from normal concentrations.
- Communication with industries about any changes in operation that could have resulted in

higher discharge concentrations.

- Grab and/or composite sampling at strategic locations in the collection system to identify potential source locations.
- Continued sampling and investigation until the source is identified and mitigated.

The pollutant tracking strategy should be incorporated into the larger diversion and off-spec plan for the AWTP so that early notification of a potential upset can lead to quick action at the AWTP. The strategy should also identify how corrective action should be taken after a contaminant event occurs.

5.3.2 Step 10. Develop Robust Sampling and Monitoring Plan

At this point in the framework, the utility has committed significant resources to sampling campaigns at the WWTP, at industries, and potentially at locations within the collection system. The baseline sampling that has been discussed in previous steps identifies potential contaminants of concern and characterizes industrial dischargers. This current step marks the transition from baseline sampling into an ongoing sampling and monitoring plan. It is important that samples continue to be taken leading up to the AWTP coming online and into operation.

The following recommendations are provided for the sampling and monitoring plan:

- After the baseline sampling campaigns (8-12 WWTP samples and 3 samples at each industry) are completed, the utility should:
  - Review the data. If there are contaminants included in the initial sampling plan that were not detected at meaningful concentrations, the utility should consider removing them from the sampling program as described in Step 5.
  - Identify the frequency of continued WWTP and industry sampling leading up to startup of the AWTP. Ongoing quarterly WWTP sampling may continue to provide value during project construction but in some cases may not be necessary. Additional industry sampling prior to AWTP startup is likely only needed for challenging or high-risk industries.
- As the project nears startup, the utility should prepare a detailed sampling plan for the project as a whole and it should be inclusive of the Industrial ESCP elements. These include:
  - WWTP sampling (secondary or tertiary effluent and potentially also raw wastewater influent) for the contaminants of concern that were identified in Phase 2. This should be performed at a frequency to maintain a consistent data set (i.e., quarterly) and should be coordinated with sample dates at the AWTP so that contaminants can be tracked through the system.
  - Industry sampling for the challenging or high-risk industries at a frequency that aligns with other sampling at the industry.
- Online monitoring should be considered as part of the monitoring plan. Online monitoring for ESCPs is being investigated as part of WRF project 5048 (Salveson forthcoming). This provides detailed recommendations on setting up an online monitoring program and the challenges with setting up and maintaining the analyzers. High-level recommendations include identifying:

- Which online analyzers can be located at the WWTP (primary effluent or secondary effluent are often used) that can determine the suitability of the influent wastewater. Potential analyzers include pH, conductivity, and TOC or UV254. While these will not directly measure a specific event in the collection system, they might be able to indicate an upset that should be investigated. If the utility is able to correlate contaminants of concern with an online analyzer value, it can be very helpful for the potable reuse program.
- If any online analyzers can be located at strategic locations within the collection system that can provide an early warning of an event. Implementation within the collection system can be challenging so it is recommended to only install permanent sensors for critical criteria. A mobile apparatus that can be moved around the collection system during an event is often more valuable and easier to maintain.
- If any online analyzers should be located at the discharge location of specific challenging industries, either monitored directly by the industry or located immediately downstream of their discharge into the sewer and monitored by the utility (unknown to the industry). Some utilities have added this to an industry permit and required the industry to maintain the analyzer and report the online data. These could include conductivity, VOC, pH, TOC, or others.

- At a defined frequency (every 5 or so years) or whenever significant changes occur in the collection system, the utility should revisit Step 5 to identify if there are new contaminants that should be included in the sampling program and to perform new rounds of baseline sampling. This will allow the utility to review new contaminants of concern or to identify contaminants that have entered the collection system since the last baseline sampling was performed.
- This sampling program will result in a tremendous amount of data. It is recommended to set up templates to review the data similar to the example shown in Step 9, above. This allows the utility to monitor the load-based contribution of contaminants of concern by various industries as more data is collected.

5.3.3 Step 11. Finalize Industrial ESCP for Permitting and Implementation

Steps 1-10 have identified the key items needed to establish a successful Industrial ESCP. In this next step, the Industrial ESCP is formalized, combined with the full ESCP that includes considerations for residential and commercial dischargers, and, if necessary, submitted to a regulatory agency. Most importantly, it is circulated to the project stakeholders and action items are divided up to responsible parties. The Industrial ESCP should include:

- Project stakeholders and key aspects of the interagency agreements, if applicable
- Technical, Managerial, and Financial (TMF) capacity to support the program
- Summary of baseline sampling results
- Identification of contaminants of concern and challenging or high-risk industries
- Results of risk analysis
- Proposed risk mitigation measures (additional treatment barriers, critical control points, WWTP or AWTP operation or controls, emergency response plan, etc.)
- Pollutant tracking strategy for each contaminant of concern
- Site-specific or local limits adjusted for the potable reuse program

- Ongoing sampling and monitoring plan
- Stakeholder engagement and communication plan
- Continuous improvement and ongoing operational plan

> The 2021 CA DWR DPR Addendum suggested that a Water Safety Plan be submitted for DPR projects and should provide the following information that all utilities should consider providing:
>
> - A comprehensive hazard analysis that considers all steps in a drinking water supply chain from wastewater source to consumer.
> - The risk management control(s) that are necessary beyond the State regulations for all DPR systems, including treatment effectiveness, critical limits, monitoring, corrective action in case of a lapse of control and an operations plan for the control(s).

5.4 Phase 4: Industrial ESCP Implementation

As the AWTP approaches startup, it is important to begin integrating the ESCP, both industrial and non-industrial components, into the project and implementing the program. Figure 5-8 presents an overview of Phase 4, which is the final phase of the framework.

INDUSTRIAL ESCP IMPLEMENTATION	Permitting or Design Phase (~1 year before project)
12. Implement an Industrial ESCP Advisory Team 13. Implement Industrial ESCP • Annual evaluation, audit, and continuous improvement plan • Monitoring, responses, and corrective action plans for contaminants of concern • Stakeholder management, communication protocols, and enhanced public education outreach • Documentation and reporting • Communication and recognition plans for industries	

Figure 5-8. Industrial ESCP Implementation.

5.4.1 Step 12. Implement an Industrial ESCP Advisory Team

This step includes the formation of an Industrial ESCP Advisory Team, which should include key project stakeholders for all represented agencies, and certainly members representing the pretreatment program, wastewater treatment, advanced treatment, and regulatory/compliance. This team is not intended to be a committee in name only; it should be empowered to recommend and implement changes both in source control and treatment to help safeguard public health as new risks are identified. It is recommended that the Industrial ESCP Advisory Team be incorporated into the larger ESCP Advisory Team that evaluates non-industrial components of the ESCP.

The purpose of this team is to provide scheduled and as needed review of system status (e.g., violations, enforcement, changes, etc.), project drivers (e.g., permitting, etc.), monitoring and emergency protocols, and other related items that are determined to be priorities to safeguard public health and promote a successful potable reuse project. This team should meet quarterly for the duration of the project.

5.4.2 Step 13. Implement Industrial ESCP

Once the utility has made it to Step 13, the resources have been planned, the risks have been identified (and hopefully mitigated), and a team has been identified to implement the Industrial ESCP. This step is to memorialize that it is not enough to just "make a plan," the plan must also be implemented and continually improved.

While the Industrial ESCP Advisory Team will be meeting every quarter to discuss system performance, ownership of the plan should be the responsibility of a single individual or a small, dedicated team. This person or team will track action items and make sure that necessary actions are being implemented.

Implementation of the Industrial ESCP is a repetition of Steps 5 through 10 and requires a focus on continuous improvement. It involves continually identifying what contaminants might pose a risk to the potable reuse system, locating key sources, and finding ways to reduce or eliminate the discharge of the contaminants. It involves constant communication with other stakeholders. It involves building strong, trusted relationships with the industries that are now a closer part of the drinking water cycle. Additional recommended aspects of the Industrial ESCP include:

- A recognition plan for industries that demonstrate consistent compliance (see Section 3.3.5).
- Annual documentation of the Industrial ESCP, including tracking contaminants of concerns and other risk factors and recording key actions taken. This may or may not be submitted to a regulatory agency.
- An updated list of permitted industries.
- Annual continuous improvement audits of the program to identify if additional resources are needed to be successful.

CHAPTER 6

Summary and Recommendations

The central goal of this project was to identify the industrial contaminants that have the highest risk of interfering with or passing through advanced treatment and causing challenges to potable reuse systems. A total of 262 contaminants were identified that have known or expected health impact and are potential contaminants for industrial discharge. These contaminants were evaluated for chemical properties, health risk, and fate through various treatment steps, and an Industrial Contaminant Screening Score (ICSS) was developed for each contaminant that prioritizes them for three different advanced treatment trains. Utilities can use the ICSS values together with site-specific sampling data (and pilot removal data if available) to create Industrial Contaminant Risk Quotient (ICRQ) values that identify the relative risk of each contaminant specific to each system. The ICSS and ICRQ calculations make up a significant part of the framework for Industrial ESCPs, which provides utilities a step-by-step process to developing an industrially-focused ESCP that identifies and mitigates the risk of industrial contaminants and can be incorporated into the ESCP for the full project.

Several additional key efforts were summarized in this report, including:

- Identifying pass-through and interference risks for three common potable reuse trains.
- Compiling a database of 262 contaminants with chemical properties, removal through advanced treatment, toxicity, and potential industrial sources.
- Identifying the prevalence of industries contributing to WWTP collection systems and common aspects of pretreatment programs through a widespread survey.
- Estimating the incremental cost of establishing ESCPs for both small utilities and large utilities.
- Providing examples of interagency agreements between water utilities that are required to demonstrate an ESCP and wastewater utilities that have to implement the ESCP.
- Documenting best practices in developing ESCPs, including how to develop and implement site-specific limits.
- Combining recommendations from various research studies to provide a step-by-step framework for developing Industrial ESCPs.

There are currently a small number of utilities operating a defined potable reuse facility and the ESCP practices vary across each. As more utilities begin planning and operating potable reuse systems, it is recommended that future ESCPs follow the guidance provided in this report so that there is more consistency and uniformity across the country in how ESCPs are implemented. This will also create a feedback loop as the potable reuse community will learn more about specific industries and contaminants as more potable reuse systems come into operation, thus providing more knowledge to further refine the recommended framework. More than anything, it is recommended that utilities share their best practices and lessons learned with others so that utilities and practitioners can collectively advance together.

A fully comprehensive industrial contaminant evaluation was not possible due to the magnitude of contaminants in existence, the lack of knowledge (both toxicology and treatability) on these contaminants, and the lack of information on industrial dischargers. While this report was able to include a significant number of contaminants in this evaluation, there is still more work to be done. The following areas are recommended for future research:

- Contaminant toxicology: prioritize the toxicological evaluation of existing and emerging contaminants so that they can be prioritized accordingly.
- Contaminant fate through treatment: improve the understanding of the fate of existing and emerging contaminants through different advanced treatment processes.
- Contaminant sourcing: collect samples across a variety of industries and identify the contaminants that are typically discharged by different types of industries. This is relatively well-known for pretreatment and conventional wastewater treatment purposes, but contaminants relevant for potable reuse are not as well understood and linked to industries.
- Industrial contaminants: this project evaluated the impact of 262 industrial contaminants that have been identified by different regulations, guidelines, or lists. However, this effort does not encompass all of the industrial chemicals that are discharged into wastewater collection systems. A more comprehensive effort is needed to identify all contaminants used or discharged by major industries and the toxicological impact and treatability of each contaminant. While this may not be possible to do for all industries, it may be possible for a single utility or collection system.
- Framework for non-industrial dischargers: this project focused only on industrial dischargers. However, a full ESCP will include considerations for residential and commercial dischargers. A robust framework for developing these aspects of the ESCP would be beneficial to the industry.
- Recommendations for challenging industries: there are a small number of industrial categories that present a disproportionate risk to potable reuse systems, including metals finishing, landfills, and CWTs, as identified in the potential sources of hazard contaminants and the results of the survey and case studies. Specific research should be conducted on these three industries to develop uniform recommendations for how utilities should approach an ESCP if these industries are in its collection system.
- Compilation of best practices: as more utilities begin operating potable reuse systems, a compilation of best practices and lessons learned for ESCPs would be valuable for the industry. While this project included case study interviews, only two utilities interviewed have operational potable reuse systems. Once more utilities have systems online (in 5 or more years), a comprehensive summary of best practices and lessons learned from 10 to 20 utilities with ESCPs would be helpful to the industry.
- Roadmap for local limits implementation: one of the most challenging topics for ESCPs is how local limits will be implemented. It would be helpful for the industry to have a document that (1) details case studies at 5-10 locations where local limits were implemented to support potable reuse projects, including how the limit was developed and the response by the industry; and (2) summarizes the legal authority of different states in implementing local limits for potable reuse as this varies across the United States. A consolidated document would help new projects and states understand how local limits are being implemented for potable reuse projects across the country.

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